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THE

PHYSICAL REVIEW.

THEORY OF THE ELECTRODELESS RING-DISCHARGE.

By Bergen Davis.

THE object of these experiments was to determine the minimum electrical intensity (volts per cm.) that is necessary to start the white electrodeless ring-discharge in gases at various pressures.

This form of electrical discharge, although obtained many years ago by Professor J. J. Thomson,[1] has not been the object of much research since the rise of the modern ionic theory of the passage of electricity through gases.

The electrodeless discharge is more simple in appearance and in constitution than the better-known discharge in vacuum tubes between electrodes. It is free from the complex phenomena of the cathode and Faraday dark spaces and the striated positive column. It is continuous and uniform in structure around the vessel along the same line of electric-intensity.

The kind of discharge that was produced in these experiments will be called white discharge. The nature of the white discharge and its differentiation from the preliminary discharge will be explained in the latter part of this paper under the title, "Appearance of the Discharge."

Results Obtained.

As a result of the experiments I have been able to determine the following properties of the electrodeless ring-discharge:

[1] Recent Researches, p. 96.

1. The minimum volts per cm. acting around a vessel that are just necessary to start the white discharge at various pressures.

2. The existence of a minimum discharging potential for each gas occurring at a certain pressure. This minimum pressure and potential will be referred to as the critical point.

3. The critical point (both potential and pressure) is dependent on the frequency of oscillation of the Leyden jar system.

4. The starting electrical intensity is *dependent* on the frequency of oscillation for all pressures below the critical point, but is *independent* of the frequency for all pressures above the critical point.

5. The ratio of the mean free path of an electron to that of a molecule.

6. The number of volts through which an electron must freely run to acquire sufficient energy to ionize a molecule by impact.

APPARATUS AND METHOD OF EXPERIMENT.

The arrangement of apparatus and method of experimenting were as follows:

Two or more Leyden jars LL' (Fig. 1) were connected with their inner coatings to the spark gap S, and also to the terminals of a large eight-plate Toepler-holtz static machine. The outer coatings

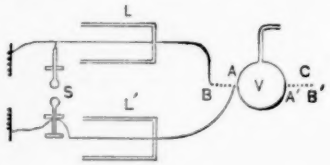

Fig. 1.

of the jars were joined to the coil c surrounding the vessel V in which the discharge was produced. This vessel was a glass globe, which was joined to an air-pump furnished with suitable drying materials and a McLeod gauge.

The spark gap consisted of two polished brass balls one centimeter in radius each. They were mounted with a micrometer screw by means of which their distance apart could be read with accuracy. This distance was converted into sparking potentials by means of Paschen's tables.[1]

[1] Wied. Ann., 37, 1889.

The coil c consisted of six turns of insulated wire wound spirally about the vessel carefully in the plane of the coil. The spiral winding was adopted to prevent any electromotive force due to the impedance of the coil from acting through the gas.

The criticism of Professor Thomson's experiments with the electrodeless discharge has been made by E. Lecher,[1] that when several turns of wire wound along the axis are used to produce the discharge, the impedance of the coil will cause a difference of potential between the end turns, and thus produce a static discharge in the gas in a direction perpendicular to the true ring discharge. The coil used in these experiments was purposely wound in a plane perpendicular to its axis in order to avoid this effect. If the coil be wound as shown in Figs. 1 and 2, the impedance will develop an electromotive force between the inner and outer turns, *i. e.*, between AA' and BB'. There will be but a small static effect across the vessel between A and A'. The only electro-motive force of magnitude to which the gas is subjected is a circular one parallel to AA' arising from the variation of the magnetic field. The discharge can easily be obtained with coils wound in this manner. I am unable to agree with the conclusion of E. Lecher and A. Steiner[2] that the ring discharge cannot be produced without the static field due to the impedance of the coil.

The value of the electrical intensity acting on the gas at the inner side of the wall of the vessel was found in terms of the sparking potential at S, by calculation from the dimensions of the vessel and coil, and the self-induction of the coil and the capacity of the Leyden jars.

On the passage of the spark at S, an oscillating current will flow through the coil C. The electro-motive force developed will be

$$\text{Curl } X = -\frac{1}{v}\frac{\partial H}{dt},$$

where $\partial H / dt$ is the variation of the magnetic field with the time, and v is the ratio of the electrical units.

The value of $\partial H / dt$ for any point within the coil may be found.

[1] E. Lecher, Wien. Bir., **112**, VII.

[2] A. Steiner, Wien. Sitz-b., CXIII., B. II.

Fig. 2 shows a plan of the coil and the vessel. The mean radii of the separate turns of the coil were as follows:

$R_1 = 9.3$ cm. $\quad R_4 = 8.58$

$R_2 = 9 \quad R_5 = 8.34$

$R_3 = 8.82 \quad R_6 = 8.1$

The inner radius of the vessel was $r = 6.4$ cm.

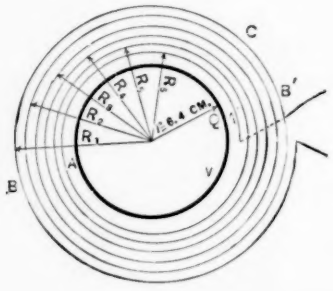

Fig. 2.

The field H at a point Q can easily be obtained in terms of the current γ and the dimensions and is given as follows:

$$H = \sum_1^6 \frac{\gamma R}{R^2 - r^2} f(E). \qquad (1)$$

Where $f(E)$ is an elliptical function of the dimensions of coil and vessel.

The variable current comes from the discharge of the Leyden jar system. The current of such a discharge is given by Prof. J. J. Thomson[1] as

$$\gamma = \frac{CP}{\sqrt{LC}} \sin \frac{t}{\sqrt{LC}}. \qquad (2)$$

Substituting in (1)

$$H = \sum_1^6 \frac{R}{R^2 - r^2} f(E) \frac{CP}{\sqrt{LC}} \sin \frac{t}{\sqrt{LC}}. \qquad (3)$$

Where P is the potential to which the jars are charged at moment of passage of sparks at S. C is the capacity and L the self-induction of the system.

[1] Recent Researches, p. 95.

Introducing the dimensions in the above, differentiating and summing :

$$\text{Curl } X = -\frac{8.42}{\upsilon}\frac{P}{L}\cos\frac{t}{\sqrt{LC}}, \tag{4}$$

where υ is the ratio of the electrical units. The average value of the above harmonic force is

$$\frac{X}{P} = -\frac{2}{\upsilon\pi}\frac{8.4}{L}, \tag{5}$$

supplying the value of L it becomes

$$\frac{X}{P} = -.00165. \tag{6}$$

Equation (6) gives the ratio of the electrical intensity acting on the gas to the potential at the spark gap. This ratio is independent of the capacity of the Leyden jars. The periodic time depends both on the capacity and self-induction, hence it was possible, by changing the capacity, to alter the frequency without changing the above ratio.

Great care was taken in determining both the capacity and self-induction of the system as mounted in position for experiment. The self-induction was measured by a double-wire Wheatstone bridge especially designed to compare small inductances. The capacity was measured by direct comparison with a standard by means of a sensitive ballistic galvanometer.

The coefficient of self-induction thus found was $L = 5{,}064$ cm.

The capacity for two jars arranged as in Fig. 1 was

$$C_1 = 1.608 \times 10^{-18},$$

and for six jars arranged three in parallel and two in series was

$$C_2 = 4.825 \times 10^{-18}.$$

The starting electrical intensity of the electrodeless discharge, under certain conditions, was found to depend on the frequency of oscillation. The frequency was changed by using capacities C_1 or C_2 as desired. This arrangement permitted a change of frequency without altering the ratio X/P.

The two periodic times as calculated from $T = 2\pi\sqrt{LC}$ were

$$T_1 = 5.652 \times 10^{-7} \text{ sec.}$$

and

$$T_2 = 9.788 \times 10^{-7} \text{ sec.}$$

The method of experimenting was as follows: The vessel was exhausted to about 1 mm. pressure with the coil in position around it. Sparks from the static machine were caused to pass slowly at S, and the spark gap was lengthened until a white discharge appeared in the vessel. Care was taken to allow the sparks to pass at rather long intervals, as it was found that the potential of the discharge depended on the rapidity of the sparks in a marked degree.

Measurements of the starting electro-motive force at various pressures were made in air, carbon-dioxide, hydrogen and helium. The carbon-dioxide and hydrogen were produced by the usual chemical methods and were washed and dried before introduction into the vessel. The helium was obtained by the dry heating of monazite sand. The impure gas was sparked over a caustic potash solution for a long while in the presence of oxygen. The excess of oxygen was afterward removed with stick phosphorus.

The results obtained are shown in the following curves:

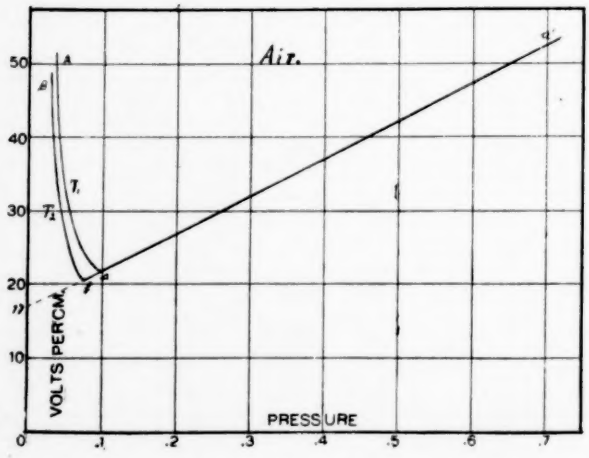

Fig. 3.

The ordinates are volts per cm., and the abscissæ are pressures in mm. of mercury. Fig. 3 shows the complete curves obtained in air for the two frequencies T_1 and T_2. Fig. 4 shows the curves

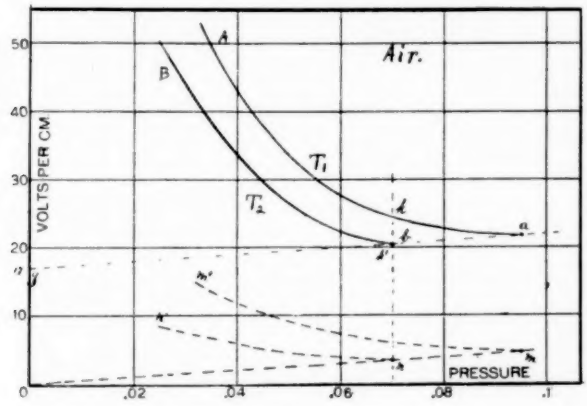

Fig. 4.

for air at pressures below the critical points drawn on an enlarged scale. Fig. 5 shows the curves for helium and carbon-dioxide, and Fig. 6 shows those for hydrogen. The results at pressures above the critical points for these gases are not shown in the figures as they gave approximate straight lines similar to the one obtained in air.

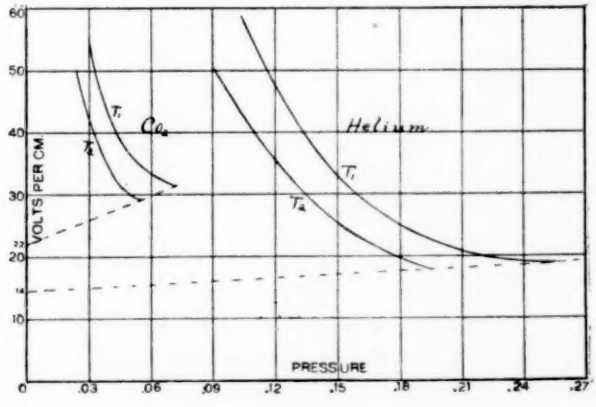

Fig. 5.

The method of measurement here used is not a very accurate one. The errors arise from the irregular potential of the spark dis-

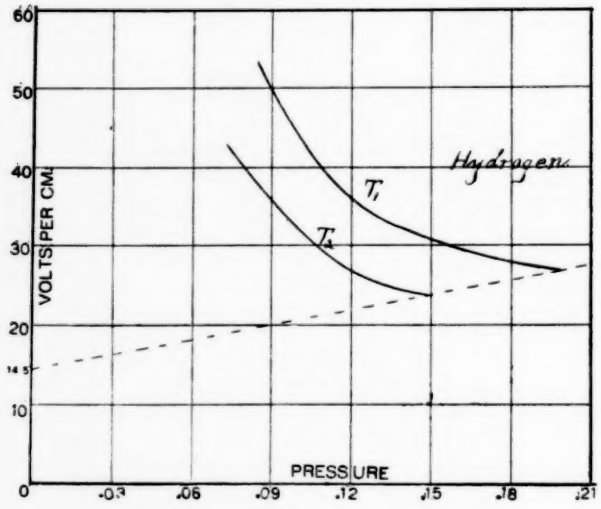

Fig. 6.

charge at S, and from the uncertainty of the appearance of the electrodeless discharge. It was found that the various readings did not differ among themselves more than ten per cent. The curves are an approximate mean of the various readings.

THEORY OF THE ELECTRODELESS DISCHARGE.

It will be observed that the discharging potential decreases with decrease of pressure to a *minimum* and then rapidly rises to the limits of the apparatus. Also the pressure and electrical intensity of the minimum points depend on the frequency of oscillation of the Leyden jar system. The electrical intensity is *independent* of the frequency at pressures above the critical point, but is *dependent* on the frequency at lower pressures.

The pressure and electrical intensity (volts per cm.) of the critical points for each gas are given in the table below:

TABLE I.

	Critical Intensity		Critical Pressure			
	T_1	T_2	T_1	T_2	A	B
Air	21.6	20.4	.095	.07	10.5	14.3
Co_2	31.2	29.3	.07	.052	10	15.4
Hydrogen	27	23.5	.205	.15	9	12.3
Helium	19	18	.255	.195	9.8	13

The mean free molecular path for each gas divided by the pressure of the critical point is nearly constant as shown by columns A and B, where A and B are for curves T_1 and T_2 respectively.

The relative mean free molecular paths of the gases experimented with are given in Meyer's Kinetic Theory of Gases as follows, taking air as unity:

Air = 1, CO_2 = .7, Hydrogen = 1.85, Helium = 2.5, for the same pressure and temperature. These numbers divided by the critical pressures for T_1 and T_2 give the constant numbers in columns A and B.

The gas, on the passage of a spark at S, is subjected to a harmonic electrical intensity X acting circularly around the vessel. During a half period this force acts in one direction, and during the next half period it acts in the reverse direction. Let T be the time the force acts in one direction (half-oscillation).

$$T_1 = \frac{1}{3540000} \text{ sec.}$$

$$T_2 = \frac{1}{2040000} \text{ sec.}$$

Ionization by Impact.

The results admit of explanation if one applies the principle of ionization by impact observed by Professor J. S. Townsend.[1]

The gas at the time of the passage of the discharge becomes highly ionized as has been shown by some previous experiments on the conductivity produced in gases by the electrodeless discharge.[2]

The ionization at low pressures takes place in *time* as is shown by effect of period of oscillation on the potential of the discharge.

Let us consider that before the passage of the discharge, when the gas is in the normal state, that there are N_0 ions present per unit volume. Also that a density of ionization N is present when the discharge appears. Both N and N_0 may vary with the pressure but have a fixed value for any one pressure. The ionization builds up from N_0 to N ions in the time T of a half oscillation.

The building up of successive ionization in a gas by impact may be expressed by the following equation:

[1] J. S. Townsend, Phil. Mag., Feb., 1901.

[2] Bergen Davis, Phys. Zeit., 4 yahrg., No. 10, 1903.

$$N = N_0 e^{\alpha a}. \tag{7}$$

Where $\alpha = \log \beta$, β is the number of ions produced by one ion at each impact including itself, and a is the average number of successive impacts which the N_0 ions make in T the time of a half-oscillation. N is the number present at moment discharge appears and N_0 is the original number present.

If X be the electrical intensity and λ be the mean path of all those ions which produce ionization by impact, then along the curves Aa and Bb in Fig. 4, the energy of the impacts will rapidly increase with decreasing pressure. The energy of impact $w = Xe\lambda$ increases, since both x and λ increase. At the minimum point the energy $w = Xe\lambda_0$ is the least that will ionize the gas at that pressure, as the pressure increases (see Fig. 3), X increases, and since λ decreases with increasing pressure, it is probable that $Xe\lambda_0$ is a constant at all pressures above the minimum.

At pressures below the critical points the intensity X will be such as to cause the N_0 ions to make a impacts in the time T. At pressures above minimum the condition of constant energy w holds. The critical point occurs at the intersection of these two controlling conditions.

Let T be the time that the force X acts in one direction, and t the average time of flight of the negative ions between impacts, then

$$\frac{T}{t} = ba \tag{8}$$

where a is the average number of successive impacts of all the N_0 ions in time T, and ba is the number of ionizing impacts of the N_0 ions in the same time. The factor b expresses the fraction of the ions that produce ionization. Also let λ equal the average path of all those ions in motion that cause ionization, then

$$\lambda = \frac{1}{2} X \frac{e}{m} t^2 \tag{9}$$

and

$$ba = T \sqrt{\frac{e}{m} \frac{X}{2\lambda}}, \tag{10}$$

from which

$$X = 2\lambda \frac{(ba)^2}{T^2} \frac{m}{e}. \tag{11}$$

At any one pressure for example along the line kk' in Fig. 4, this expression should give

$$X = \frac{K}{T^2}. \tag{12}$$

A trial shows that the actual values of X for the two curves are *not* inversely as the squares of T. We may add a constant ν_0 to the equation, such that ν_0 shall satisfy the condition

$$X = \frac{K}{T^2} + \nu_0 \tag{13}$$

when applied to the curves for any one pressure. On solving (13) for decreasing pressures it is found that ν_0 *increases* as the pressure decreases, hence we may write as an approximation:

$$\nu_0 = \nu\lambda$$

where ν is a constant.

Equations (11) and (13) become:

$$X = \lambda\left(\frac{2(ba)^2}{T^2} \cdot \frac{m}{e} + \nu\right). \tag{14}$$

This is the general equation of the electrodeless ring discharge at pressure below the critical point. It approximately represents both curves T_1 and T_2 in Figs. 4, 5 and 6.

The experimental curves do not satisfy the condition

$$X = \frac{K}{T^2}$$

for a given pressure, but if similar curves be drawn with their origins at the same pressures, and on a line *onm* drawn parallel to *abg* (see Fig. 4) passing through the origin, then these curves mm' and nn', at any pressure, do satisfy the condition

$$X = \frac{K}{T^2},$$

consequently the constant ν is equal to the distance og. It is the intersection of a straight line through ab with the axis of ordinates.

Calculation of Constants.

Equation (14) is the expression for the discharge at pressures below the minimum point. The constant ba and the average ionic

path at any pressure may be found by introducing the proper values of X for the two curves into the equation.

A solution of the equation for air at .07 mm. pressure gives

$$ba = 28, \text{ and } \lambda = .807 \text{ cm.}$$

A similar solution at .035 mm. gives $ba = 41.7$, and $\lambda = 1.07$ cm.

The value of e/m made use of in the above solution is

$$e/m = 4.6 \times 10^{17} \text{ E. S.}$$

The results of the solutions of equation (14) for all the gases at various pressures are given in the following table:

TABLE II.

Air.

Press.	ba	λ	$\frac{\lambda}{\lambda'}$	b	a	α
.07 mm.	28	.807	5.3	.57	50	.53
.05	35.5	.88	4.2	.81	43.8	.70
.035	41.7	1.07	3.6	.97	43	.80

Carbon-Dioxide.

Press.	ba	λ	$\frac{\lambda}{\lambda'}$	b	a	α
.052	36.7	.80	5.5	.56	65	.52
.04	41.5	.84	4.5	.75	55	.66
.03	50	.88	3.6	.97	51	.80

Hydrogen.

Press.	ba	λ	$\frac{\lambda}{\lambda'}$	b	a	α
.15	44.4	.67 cm.	5.3	.55	80	.52
.12	45	.76	4.7	.71	64	.63
.08	54	.91	3.7	.95	57	.79

Helium.

Press.	ba	λ	$\frac{\lambda}{\lambda'}$	b	a	α
.195 mm.	30	.75 cm.	5.5	.56	54	.52
.150	39	.83	4.7	.71	55	.63
.105	51.5	.99	3.9	.9	57	.76

The method of determining the constants a, b and α are given in a later paragraph.

The table shows that λ increases with decrease of pressure, and

that λ/λ' decreases with decrease of pressure. The mean free path λ' of a molecule at any pressure is found by calculation from the value 10^{-5} cm., given in Meyer's Kinetic Theory of Gases, for air at atmospheric pressures. The value of λ' so found is obtained on the assumption that the molecules have their ordinary speeds. Maxwell has shown that if a molecule moves with a great speed in the presence of other molecules, that its mean path will be increased $\sqrt{2}$ times. The negative ion under the force X to which it is subjected moves with a velocity of higher order than the molecules. Its average path is thus $\sqrt{2}$ greater than it would be if it moved with molecular speeds. In expressing the ratio λ/λ' the mean molecular path was multiplied by $\sqrt{2}$ in order to give the ratio of the mean path of the negative ion to that of a molecule under identical conditions of speed.

The fact that λ/λ' decreases with decreasing pressure, indicates that as the pressure becomes very low a greater part of those ions in motion take part in the ionization. The constant b in the above table expresses the fraction of total ions at any time that have enough energy to produce ionization. If the energy of ionization is w, all those ions which make a path greater than λ_0 in $w = X\epsilon\lambda_0$, produce ionization.

The λ in the above tables is the mean path of all those ions which make a path greater than λ_0.

The kinetic gas theory may be applied to these moving ions. By this theory [1] if N be the number of ions in motion, then the sum of all the paths before collision is:

$$N\int_0^\infty \frac{x}{l} e^{-\frac{x}{l}} dx = Nl \tag{15}$$

Where l is the mean of all the paths and x is any path. The sum of those paths greater than λ_0 is

$$N\int_{\lambda_0}^\infty \frac{x}{l} e^{-\frac{x}{l}} dx \tag{16}$$

The number of paths which exceed the length λ_0 is

$$Ne^{-\frac{\lambda_0}{l}}$$

[1] Meyer's Kinetic Theory of Gases, p. 408.

The average path λ of all those ions which make a path greater than the path λ_0 is

$$\lambda = \frac{N\int_{\lambda_0}^{\infty} e^{-\frac{x}{l}} \frac{x}{l} \cdot dx}{Ne^{-\frac{\lambda_0}{l}}} = l\left(1 + \frac{\lambda_0}{l}\right) \qquad (17)$$

For the sake of clearness it may be excusable to reproduce the following curve of distribution of probable paths in a gas:

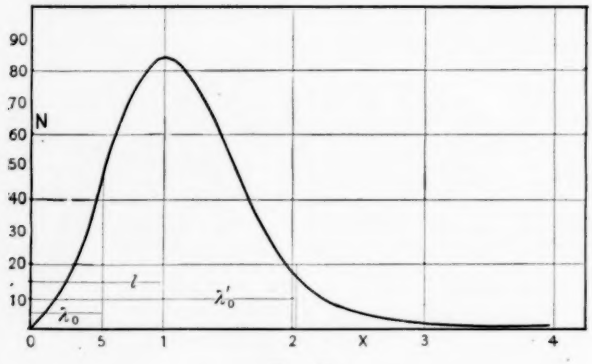

Fig. 7.

The ordinates represent the probability of an ion making the path x before collision.

MEAN FREE PATH OF AN ION.

At the minimum point all those ions which exceed a path λ_0 produce ionization, and λ is the mean of those paths which exceed λ_0. The ratio

$$\frac{\lambda}{\lambda^1} \qquad (R)$$

at the critical point, is the ratio of average path of those ions to the mean path of all the molecules. At the low pressure at which the discharge ceases

$$\frac{\lambda}{\lambda^1} \qquad (S)$$

is still the ratio of the ionizing paths to the mean path of all the molecules. The ratio is 5.3 (for air) at the critical point and is only 3.6 at the pressure at which the discharge ceases. This shows that at

the critical point many of the ions have too short a path to cause ionization by impact. At very low pressures an increasing proportion of the ions take part in the ionization.

The average value of the ratio

$$\frac{\lambda}{\lambda'} \qquad \text{(S)}$$

for all the gases at the lowest pressure is 3.7. Prof. J. S. Townsend[1] obtained from experiments on ionization by impact the ratio of the mean free path of a negative ion to that of the molecule as 4.3. He also points out that from theoretical considerations, a particle of much smaller dimensions than a molecule, should have a path four times that of a molecule under similar conditions, provided it had no charge. The effect of charge would be to increase the sphere of action and make the ratio λ/λ' less than four. The average ratio $\lambda/\lambda' = 3.7$ obtained above must be greater than the actual ratio, since even at these low pressures a few of the ions must have too small a path to cause ionization by impact. The ratio of the ionic to the molecular mean free path cannot be much less than 3.7. The value $\lambda/\lambda' = 3.5$ may be taken as an approximation to the true ratio. The symbol l is used throughout for the mean path of all the ions.

Least Energy of Ionization by Impact.

The application of the kinetic theory enables one to determine the least energy $w = X\epsilon\lambda_0$ that an ion must have to produce other ions by impact. The results for air will be followed through as an example. At the critical point .07 mm. pressure the value of λ obtained is .807 cm. This value is substituted in equation (17) which gives $\lambda/l = .54$. Now all ions making a path greater than λ_0 ionize by impact. All ions in air having a path greater than about one half the mean path l cause ionization. This is graphically shown in Fig. 7, where λ_0 is shown its relation to l. In a previous paragraph it was shown that $l = 3.5\lambda'$ approximately. The values of λ' the mean free molecular path at .07 mm. is .15 cm., from which the absolute value of λ_0 is $\lambda_0 = .54\ l = .28$ cm. The value of X at .07 mm. pressure is 20.5 volts, hence the least free electrical

[1] J. S. Townsend, Phil. Mag., Feb., 1901.

intensity through which the ions run is $X\lambda_0 = 5.7$ volts. Similar calculation may be made for the other gases. The results are given in table III.

The least energy of impact may be found by $w = Xe\lambda_0$.

The value of e which I have chosen is that obtained by H. A. Wilson.[1] The mean of his measurements is $e = 3.1 \times 10^{-10}$ E.S. units.

TABLE III.

Gas.	l	λ_0	X	$X\lambda$	$w = Xe\lambda_0$
Air (.07).....	.52 cm.	.28 cm.	20.5	5.7	5.7×10^{-12} ergs.
Co_2(.052)	.51 "	.3 "	29.3	8.8	8.8×10^{-12} "
H_2(.15)	.44 "	.23 "	23.6	5.2	5.2×10^{-12} "
Helium (.195)...	.47 "	.28 "	18	5	5×10^{-12} "

It will be observed that the mean path l of all the negative ions at the critical pressure is nearly a constant for all the gases. The energy of ionization by impact w is also nearly constant for air, hydrogen and helium, but is somewhat greater for carbon-dioxide.

Professor J. S. Townsend found by an entirely different method that a negative ion must freely run through 5 volts to obtain the necessary energy to ionize by impact. The above result (5.7 volts) agrees well with his experiments. J. Stark[2] gives as his estimate of the necessary free run of an ion about 50 volts. Professor Rutherford and R. K. McClung[3] from experiments on the ionization of air by Röntgen rays consider that an ion must run through about 175 volts. Their result is based on the assumption that all the energy of the rays is consumed in producing ionization. It is probable that much of the energy is dissipated in the form of heat. It is difficult to reconcile the starting electromotive force of the discharge as found by my experiments with such high values for the energy of ionization by impact.

CALCULATION OF THE CONSTANTS a, b AND a.

At the critical point, say, .07 mm., taking air as an example, the number of negative ions having a path greater than λ_0 is

[1] H. A. Wilson, Phil. Mag., April, 1903.
[2] J. Stark, Die Electricität in Gasen, p. 57.
[3] Rutherford & McClung, Phil. Trans., 146, 1901.

$$n = Ne^{-\frac{\lambda_0}{l}}.$$

The fraction of the total number N engaged in producing the ionization is

$$b = \frac{Ne^{-\frac{\lambda_0}{l}}}{N} = e^{-\frac{\lambda_0}{l}}. \qquad (18)$$

Only that portion of the N_0 ions in equation (7) that have a path greater than λ_0 will produce ionization by impact. The β in the equation $a = \log \beta$, may be written $\beta = (1 + b)$, and a becomes

$$a = \log (1 + e^{-\lambda_0/l}).$$

The value of λ_0/l may be obtained from Table III. Substituting in the above equation, the values of a given in the last columns of the tables are obtained. The value for a is obtained directly from the values of ba and b previously found.

THE DISCHARGE AT PRESSURES ABOVE CRITICAL POINT.

The curve for air at pressures above the critical points is shown at baa' in Fig. 3. It is a straight line not passing through the origin of coördinates. Similar straight lines were obtained for the other gases, but are not shown in the figures. This straight line for air, when extended cuts the axis at 17 volts. The condition of constant energy $w = Xe\lambda_0$ all along this curve requires that it should pass through the origin if the same proportion of the moving ions produce ionization at .7 mm. as produce it at .07 mm. pressure. The fact that the curve extended does not pass through the origin indicates that the ionizing path λ does not decrease as rapidly as the pressure increases. If the energy is constant then $X\lambda_0 = X'\lambda_0'$, where $X\lambda_0$ is for the critical point .07 mm. and $X'\lambda_0'$ is for another point on the line, say at .7 mm. pressure. The value of λ_0 at .07 mm. has been previously found to be $\lambda_0 = .54l = .28$ cm. (see Table III.), where l is the mean path of all the electrons at b. The value of λ_0' at a' is

$$\lambda_0' = \frac{X}{X'}\lambda_0 = .21l,$$

but l here is mean path at .07 mm. pressure. Let l' be the mean

path of all the ions at .7 mm. pressure. Since l' decreases proportionately with the increase of pressure, $l = 10l'$ and $\lambda_0' = 2.1l'$. That is all those ions, and those only produce ionization at .7 mm. pressure, that have a path twice as great as the mean path. This is represented in Fig. 7, where λ_0 is the least ionizing path at .07 mm., and λ_0' is that at .7 mm. pressure. As the pressure increases the line representing λ_0 moves out from the origin. As the pressure increases a continually decreasing proportion of the ions take part in the ionization by impact.

The straight part of the curve ba' if exterpolated to atmospheric pressure (760), gives $X' = 37{,}000$ volts per cm. This is about the same as the sparking potential between plates one cm. apart at ordinary pressures. If it were possible to produce an electrical intensity of 37,000 volts by the methods here used, the electrodeless discharge could be obtained at atmospheric pressure.

IMPACT OF NEGATIVE IONS ONLY.

In the foregoing theory all the ionization has been considered to be due to impact of negative ions only. An inquiry will now be made to ascertain if some of the ionization may not have been caused by the impact of positive ions.

While the harmonic electric force was acting on the negative ions in one direction an equal force was acting on the positive ions in the opposite direction.

At the critical point the value of $X\lambda_0$ was just great enough to give the negative ions the required ionizing energy w in moving through their path λ_0 at that pressure. The mean free path of a positive ion is of the same order as that of a molecule, and is a little greater than one fourth of that of the negative ion. If the required energy of impact of a positive ion is the same as that of a negative ion, then only those ions will cause ionization which have a path 3.5 greater than the λ_0 for negative ions at any pressure. At pressures below the critical points along the curves Aa and Bb, X/p increases rapidly to a great value. The positive ions would acquire more than the required energy in going between successive impacts at very low pressures. However, the period of oscillation is so small that owing to their great mass the positive ions can go only

a small part of the required path in the time T of a half oscillation, On the other hand the negative ions make a successive impacts in the same time.

In developing equation (3) we have

$$a = \log \beta.$$

If the positive ions made impacts in the same time as the negative then

$$a = \log (\beta + \beta'),$$

where β' is the number of ions produced by one positive ion at each impact including itself. The positive ions go a much less distance in a given time than the negative ions. While one negative ion is moving between two successive impacts and producing β ions, the number of ions produced by impact of a positive ion in the same time is

$$\beta' = \beta e^{-\left(\frac{M}{m}\frac{\lambda'}{l}-1\right)}. \tag{19}$$

Where M and m are the masses of the positive and negative ions respectively, and λ' and l are the mean free paths of the positive and negative ions. The complete expression for a in equation (3) is

$$a = \log \beta \left[1 + e^{-\left(\frac{M}{m}\frac{\lambda'}{l}-1\right)}\right]. \tag{20}$$

If M were so small as 3.5 m., then $a = \log 2\,\beta$ and the electric intensity required to build up the ionization from N_0 to N ions would be very much less than that observed.

For hydrogen, whose positive ion has the least mass of any gas the above exponent is -300 approximately.

Even with a positive ion with so little mass as that of hydrogen, the ionization by impact of *positive* ions is infinitesimally small.

The Effect of Rapid Sparking.

The effect of the rapidity of the passage of the sparks at S, upon the starting intensity was very marked. If several sparks were allowed to pass per second, then a much smaller value of X was obtained than if a long wait were made between the sparks. This effect was most marked at low pressures, especially near the pres-

sure of the critical point. The decrease in starting intensity due to this cause was much less at higher pressures.

A series of experiments on the electrical intensity required to produce the electrodeless discharge was made by the writer more than a year ago at the Cavendish Laboratories. In these experiments an induction coil was used to charge the Leyden jar system. This coil was driven by an alternating current at 90 periods per second. This gave 180 sparks per second at the spark gap. The curves of starting potential obtained by this apparatus were similar to those obtained by a single spark, but the values of X for any pressure were very much smaller. The critical points bore about the same relation to the frequency of oscillation as that obtained by the single spark.

This effect supports the theory that the ionization builds up from N_0 to N ions in producing the discharge. If N_0 is very large when the spark passes, then a smaller value of X will be required, since a less number of impacts will be necessary in going from N_0 to N ions.

Also suppose X too small to give discharge at first spark, then, at first spark N_0 will build up to N_1 say, and before the next spark, they will recombine to N_0' and at next spark build up to N'', and so on at each successive spark until the necessary N ions are present. The discharging electrical intensity will thus depend both on the number of sparks per second and the rate of recombination of the ions.

The rate of recombination at low pressures appears to be much slower than at atmospheric pressure. After the discharge had been once produced in the gas it could be obtained immediately afterward with a much smaller intensity. A wait of several minutes was sometimes necessary before the gas recovered its normal state.

BEHAVIOR OF HYDROGEN.

Hydrogen gave anomalous results when subjected to rapid sparking. Thus for a single spark the critical points for each gas bear a certain constant relation to the mean free path of a molecule at that pressure.

This law held true for air, carbon dioxide and helium, even when

subjected to 180 sparks per second. The pressure of the critical point, for hydrogen, was altered very much by the rapidity of sparking. When subjected to rapid sparks, the minimum point occurred at less than half the pressure that was obtained by single sparks. Below the critical points the increase in X was very slow, so that the discharge could be obtained with ease at lower pressures than was possible with single sparks.

The spectrum of the hydrogen was very impure at these low pressures. The mercury lines were very prominent. Even at high pressures the mercury lines were visible. As the pressure was reduced the mercury lines became brighter, until at low pressures the hydrogen lines became very faint and the discharge appeared to pass almost entirely through the mercury vapor present. This effect was not stopped by the insertion of a plug of gold leaf between the vessel and the pump.

This effect appears to agree well with the molecular-weight law of distribution of current in mixed gases recently advanced by P. G. Nutting.[1] He found that the current as indicated by the brightness of the spectrum, was distributed in mixed gases proportionately to the molecular weights. It is possible that the anomalous effect described above may have been caused by the current passing principally through mercury vapor and not through hydrogen.

Appearance of the Discharge.

In this paper the term "white discharge" has been employed. The white discharge may be produced in all the gases with which I have experimented. Two kinds of discharge may be obtained at all pressures above the critical pressure. At high pressures with weak fields a milky-white, rather tenuous discharge was obtained in both air and carbon-dioxide. Air must be very dry to give a whitish preliminary discharge. The least trace of moisture gives it a reddish tinge. When the electrical intensity was increased the density of this whitish discharge increased and suddenly changed to the bright light of the white discharge. The electrical intensity measured in these experiments was such as to give a bright white discharge of considerable density.

[1] P. G. Nutting, Astrophysical Journal, 19, March, 1904.

The preliminary discharge in helium was yellowish red, which changed to a full white when the intensity was increased.

A very brilliant afterglow was also observed in helium. This afterglow was most brilliant at pressures above the critical points. It was very faint at very low pressure. It was very brilliant and remained visible for many seconds after the passage of the discharge. The spectrum of this afterglow could be seen very plainly. At the interruption of the discharge the glow died out and the helium lines disappeared in a certain order. The order of disappearance was: the three blue lines, the green line, the red line, and lastly the yellow line. Both the red and yellow lines were quite persistent, while the other lines vanished almost immediately.

PHŒNIX PHYSICAL LABORATORY,
COLUMBIA UNIVERSITY,
December, 1904.

THE COMPARISON OF INDUCTANCES WITH GREAT PRECISION.

By A. H. TAYLOR.

BY using potentiometer methods it is quite possible to compare even very small resistances to within 0.001 per cent. After using a double potentiometer scheme for the comparison of low resistances in a determination of small temperature coefficients of alloys, the question very naturally arose as to whether some similar device might not be used with advantage for the comparison of inductances. Strictly speaking, the method described in this paper may not be called a potentiometer method because it necessarily involves the idea of phase-displacement. The first step was to send an alternating current i_1, through a non-inductive resistance r_1, a second alternating current i_2, through a non-inductive resistance r_2, and balance the potential difference $i_1 r_1$ against $i_2 r_2$.

This is obviously impossible unless i_1 and i_2 come from separate coils on the *same* transformer, since the slightest difference in the quality of the iron of the two transformers would alter their wave-form.

Furthermore, it was found impossible to obtain an absolutely perfect balance unless the two coils furnishing i_1 and i_2 were braided together and hence wound on exactly the same place on the transformer. This entails exact equality of applied E.M.F.'s in the two circuits, as was tested by opposing the two coils in series with a telephone. If the two coils are in different places on the transformer, there will unavoidably be some magnetic leakage around them. This means that there will be different hysteresis losses in the portions of the iron inside of the two coils, especially if i_1 and i_2 are not equal. This, in turn, produces different energy components in i_1 and i_2, and a phase difference which cannot be corrected by variations of resistance and inductance in the external circuits. In other words, it is absolutely necessary that all the lines included by

i_1 in the transformer be also included by i_2, otherwise their mutual induction will produce a phase difference.

This point gave rise to many difficulties in the earlier course of the investigation, since all telephonic balances gave good minima but never perfect silence. No further difficulty from this point was experienced when the coils were braided and formed a bi-filar winding.

Unfortunately, one side of the city alternating circuit in Madison is permanently grounded, and it was early apparent that there was an alternating potential gradient running slantwise up through the room. A very sensitive Siemens and Halske telephone was used, and this static effect would usually produce a humming in the telephone before the apparatus was connected to any source of E.M.F. This difficulty was overcome by mounting on porcelain or glass insulators all parts of the apparatus and the chair of the observer.

Another difficulty lay in the fact that the lighting system gave a very poor sine wave, and the balance for the fundamental would not exactly coincide with that for the overtones. The overtones were then choked out by inserting very large inductances in series with the primary of the transformer giving i_1 and i_2.

Finally, for some balances a capacity of several microfarads was

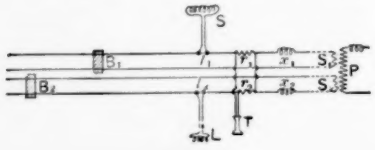

Fig. 1.

placed in parallel with the telephone, thus absorbing any higher frequencies which may have gotten through.

After making certain that perfect balances could be obtained under proper conditions, the following arrangement of apparatus was adopted (see Fig. 1).

P is the primary of the transformer, in series with a large choke coil. S_1 and S_2 are the two secondaries which are really braided and so wound on the transformer core. The transformer is several meters from the rest of the circuit, and S_1 and S_2 are connected to their respective circuits with braided leads. At x_1 and x_2 are vari-

able reactances for shifting the phase of the two circuits, while r_1 and r_2 are two non-inductive standards whose ratio was accurately determined by an Elliott Bridge. The temperature coefficient of the I. A. alloy of which r_1 and r_2 were made had previously been determined.

S is a Leeds and Northrup standard of self-induction, variable up to 40 milli-henrys, and L is the inductance to be compared. Both of these inductances were several meters away from the rest of the circuit, and connected to it by braided leads. The stray magnetic field from the standard inductance is particularly annoying in preventing a perfect balance. At l_1 and l_2 are amalgamated copper links, dipping into mercury cups and cutting out S and L respectively. Extending beyond l_1 and l_2 are two pairs of I. A. wires, one pair for each circuit, arranged so that more or less can be cut out by sliding the bridges, B_1 and B_2, thus forming smoothly variable rheostats for controlling the current in the two circuits.

In order to insure perfect contact, the bridges B_1 and B_2 are small fiber boxes filled with mercury and sealed. The rheostat wires, No. 24 in size, run through small holes in the sides of the boxes. The mercury does not noticeably attack the wires even after several months of constant use.

The telephone is connected in series with the potentials $i_1 r_1$ and $i_2 r_2$, so that the potentials oppose each other.

The method of operation is to first obtain a balance with l_1 and l_2 in place. The sliders B_1 and B_2 are moved so that the telephone indicates a minimum, and then the circuits are shifted into phase by varying x_1 and x_2.

These two adjustments are readily made simultaneously. This adjustment is usually preliminary, so as to determine what ranges are necessary for x_1 and x_2. The link l_1 is now removed and the adjustment repeated with the smallest convenient setting of S.

Finally, l_2 is removed and a balance obtained by sliding B_1 and B_2 and increasing S, *the reactances* x_1 *and* x_2 *being left undisturbed.*

If ΔS is the change in the reading of the standard,

$$L = \Delta S \cdot \frac{r_2}{r_1}.$$

This may be shown as follows :

Let X_1 and X_2 be the total reactances in the circuit and R_1 and R_2 the total resistances. Then the impedances are :

$$R_1 - jX_1 \text{ and } R - jX_2,$$

respectively. The equation of balance is :

$$i_1 r_1 = i_2 r_2.$$

Since S_1 and S_2 give equal E.M.F.'s :

$$(R_1 - jX_1)i_1 = (R_2 - jX_2)i_2.$$

Since the phase angle is the same in each circuit at balance, the coefficients of j are equal, or :

$$X_1 i_1 = X_2 i_2.$$

Hence

$$X_2 = X_1 \frac{i_1}{i_2} = X_1 \frac{r_2}{r_1}.$$

Also :

$$\Delta X_2 = \Delta X_1 \frac{r_2}{r_1},$$

since

$$\Delta X_2 = \omega L$$

and

$$\Delta X_1 = \omega \cdot \Delta S.$$

Hence,

$$L = \Delta S \cdot \frac{r_2}{r_1}.$$

The value of L may be obtained with a single setting of S by omitting the second adjustment, in which case ΔS is the setting of the standard in the final adjustment. Thus L may be determined in terms of one value of the standard or in terms of the difference of two values of S taken in different parts of the scale.

The order of precision of this method of comparing inductances greatly exceeded the accuracy with which the standard could be read. The standard was divided on one side into milli-henrys and on the other to degrees, from 0° to 180°. Tenths of degrees could be estimated with fair accuracy, yet successive adjustments gave readings of the standard as nearly alike as could be distinguished by the eye. In order to determine the limit of error, a mirror was fastened to the rotary top of the variable standard S, and a tele-

scope and scale set up at a distance of about 2.5 meters so that at the portion of the scale used, a change of one milli-henry in the setting of S rotated the mirror so as to produce a deflection, as read in the telescopes, of 50 cm.

With an equality balance, $r_1 = r_2$, the scale readings for ten successive settings of the standard are given in Table I.

The E.M.F. of the two secondaries was about four volts, and r_1 and r_2 were two standard 10 ohm coils, over which the drop is potential was about 1.5 volts.

An average deviation of .26 cm., corresponds to 5.2×10^{-6} henrys. The actual reading of S was 40 milli-henrys, or 4×10^{-2} henrys. Hence the average deviation of any one result from the mean is 0.00013 or 0.013 per cent.

TABLE I.

Scale Reading, cm.		Deviations, cm.	
10.1	10.4	0.05	0.35
10.2	9.6	0.15	0.45
9.5	9.8	0.55	0.25
10.0	10.3	0.05	0.25
10.3	10.3	0.25	0.25
Average.....10.05		Average deviation.....0.26	

It will be noted that the *maximum* deviation of any one setting from the mean is only 0.027 per cent., while the probable error of an average of ten settings is of the order of a few thousandths of 1 per cent.

The observer was necessarily unprejudiced in taking these readings, for the standard S was in one corner of the room, being operated with a string and pulley attachment, while the telescope and scale were mounted too far away to get a telephonic balance and a scale reading simultaneously. Several sets of ten readings gave very nearly the same percentage deviations. The set here given was taken in the daytime without any extraordinary precautions against noisy disturbances.

By using a pair of secondaries giving E.M.F.'s of about 2 volts, the rest of the circuit remaining the same, the average deviation of any one result from the mean was found from several sets of read-

ings to be very nearly 0.02 per cent. Needless to say, for the comparison of large inductances it is advisable to use as large E.M.F. and current as the standard resistances r_1 and r_2 can stand without changing the temperature too much.

For the comparison of very small inductances, low E.M.F.'s and very low reactances throughout are necessary. With this particular transformer the smallest inductances compared were of the order of one milli-henry, and the limit of error determined as above was 0.04 per cent. In this case $r_1 = r_2 = 0.3$ ohms.

If a small inductance be compared with a larger one, the ratio of r_1 to r_2 may be far from unity, and there is an inevitable loss of sensibility, since the current through the higher of the two standards of resistance must be cut down by series resistance until $r_1 i_1 = r_2 i_2$. In a specific case,

$$r_1 = 10 \text{ ohms.}$$
$$r_2 = 100 \text{ ohms.}$$

At L was inserted an inductance of about 160 milli-henrys, so that the standard balanced it at 16 milli-henrys. Table II. gives the scale readings for ten successive settings.

The average deviation from the mean of any one setting is here 3.86×10^{-3} milli-henrys, or 0.024 per cent.

TABLE II.

Scale Readings, cm.		Deviations, cm.	
39.5	39.6	0.02	0.12
39.05	39.1	0.43	0.38
39.6	39.3	0.12	0.18
39.6	39.7	0.12	0.22
39.6	39.7	0.12	0.22
Average ....39.48 cm.		Average deviation.....0.193 cm.	

With the ratio coils in the reverse order, *i. e.*, $r_1 = 100$, $r_2 = 10$, $S = 38$ and $L = 3.8$, the average deviation was 0.03 per cent.

Table III. gives the settings with :

$$r_1 = 100 \text{ ohms,}$$
$$r_2 = 1 \text{ ohm,}$$
$$S = 40 \text{ M. H.,}$$
$$L = 0.4 \text{ M. H.}$$

TABLE III.

Scale Reading, cm.		Deviation, cm.	
7.6	4.6	2.5	0.5
6.5	2.8	1.4	2.5
5.3	6.4	0.2	1.3
4.4	4.0	0.7	1.1
5.4	3.8	0.5	1.3
Average.....5.10		Average deviation.....1.14	

The average deviation is here 0.057 per cent., which is fairly satisfactory for a ratio of 100:1 between the inductances compared.

In several instances the coils S_1 and S_2 were tested for any possible asymmetry by getting a balance, exchanging the circuits connected with S_1 and S_2 and balancing again. The asymmetry was so little that the average settings of S were alike within the limits of error, *i. e.*, about 0.004 per cent. Ten settings of S were taken before and after the exchange.

It may be of interest to give some of the data obtained in the calibration of the standard of self-induction S. With an equality balance $r_1 = r_2$, a small arbitrary unit of inductance L was laid off in successive steps on the standard in the following manner. L was balanced against a small value of S in the usual manner. Then L

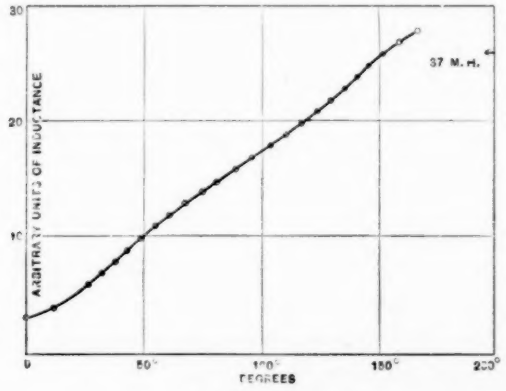

Fig. 2.

was cut out by the link l_2 and with S still in the other circuit, balance was again obtained by increasing x_2.

Then L was added again to circuit No. 2, which necessitated an

increase in S by an amount equal to L in order to balance again. This step-by-step process was repeated until twenty-five steps had been taken, bringing the reading of S to 166.2° or about 37 M. H.

Finally, with $r_1/r_2 = 25$, the twenty-five steps were taken all at once, instead of successively, bringing the reading to 166.5°.

That is, the possible additive error introduced by twenty-five consecutive settings amounted to less than 0.2 per cent. This was considered satisfactory, and the calibration curve of S in terms of the arbitrary unit L is given in Fig. 2.

By using a very slight modification of a method suggested by Professor A. Trowbridge, the standard inductance was compared with a new Elliott condenser. Several places found where it was

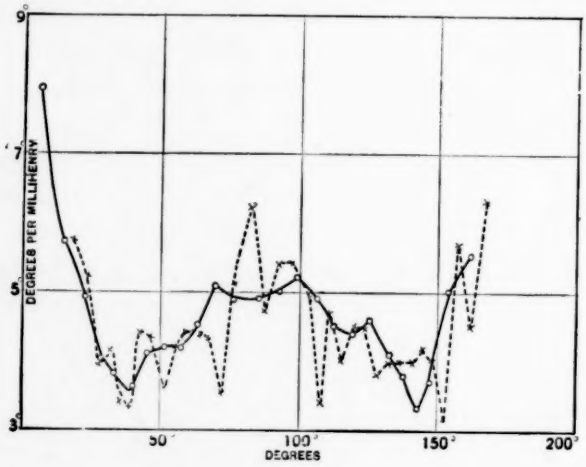

Fig. 3.

correct (relative to the condenser) as close as it could be read, and from these results the value of L was deduced and a curve plotted giving the degrees per milli-henry as a function of the scale reading in degrees. This is the full line curve in Fig. 3, while the dotted line represents the degrees per milli-henry according to the scale marked on the standard.

The general agreement between these curves, irregular as they are, is good, but there are several points where the calibration marks on the standard are displaced a little, giving two peaks to the dotted curve, whose average, however, falls nearly on the full curve, as at 80° and 165°.

In conclusion, it may be stated that this method of comparing inductances may readily be given greater precision by using higher E.M.F.'s than 4 volts, but as it is, it admits of the comparison of inductances with a precision very nearly of the same order as that with which resistances may be determined. The probable error of the mean of ten observations will be far inside of the average deviation of any one result from the mean. This deviation is less than 0.06 per cent. even with a step-down ratio of 100:1.

The method here described is peculiarly adapted to the step-by-step method of calibrating standards of inductance.

Incidentally, it would seem that a new form of variable standard of inductance is desirable; a form having less stray field, susceptible of finer calibration and provided perhaps with a vernier attachment to admit of the more accurate reading of settings.

UNIVERSITY OF WISCONSIN,
November 30, 1904.

ON THE LUMINOUS EFFICIENCY OF THE CARBON FILAMENT.

BY C. E. MENDENHALL.

ALL the published values[1] of the luminous efficiency of the carbon filament known to the writer are between 3.6 per cent. and 6 per cent. for filaments glowing with about the normal brilliancy of an incandescent lamp; and these seem obviously too high when compared with the results for other sources which have been more recently studied. The present determination has therefore

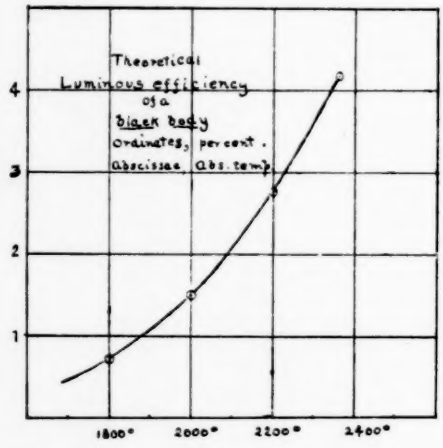

Fig. 1.

been made under my direction by Mr. W. Kunerth, a senior in this University, whose careful assistance I am glad to acknowledge.

A slight modification of Angstrom's method (for the details of which reference must be made to his to his original paper[2]) was used, as is shown in the diagram; the object being to dispense with one of the usual duplicate source of light. This obviates the diffi-

[1] Merritt, Am. Journ. Science, Vol. 37, p. 167. Blattner, quoted in Lum. Elect., Vol. 23, p. 519.

[2] Angstrom, Astrophys. Journ., Vol. 15, p. 223.

culty of maintaining two exactly equal sources, which would have been especially troublesome in the present case since the carbon filament had to be in an exhausted vessel. Since this set-up involved entirely different constituent parts, it gave good opportunity to detect any errors due to particular instrumental arrangements which might be present in Mr. Ingersol's[1] determination of the luminous efficiency of a Nernst glower. The result of the redetermination, for a given power consumption, agreed very closely with that of Mr. Ingersol.

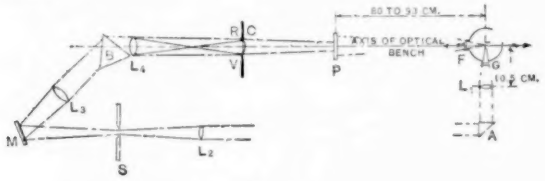

Fig. 2.

A brief description of the general arrangement of apparatus will suffice, with the aid of the diagram, to make things clear. L is a straight carbon filament, from a 100 c.p. "Mogul" lamp, 27 mm. long and 0.43 mm. × 0.95 mm. in cross section, inclosed in an exhausted brass cylinder provided with a fluorite window F and a glass window G. Light passing through G was made parallel by the lens L_1, reflected by the prism A and focussed on the spectroscope slit S by the lens L_2. The visible portion of the resulting spectrum was recombined by the cylindric lens C and fell on the Lummer-Brodhun photometer screen P. Photometric balance was obtained by moving the source L on an optical bench in the direction of the arrows, L_1 and A being rigidly connected to and moving with L. The parallel beam AL_2 having been previously adjusted parallel to the direction of motion, it is evident that the motion of L will not alter the intensity or the position of the image on S.

The energy ratio of the visible and total radiation reaching P from the two sides was determined by substituting for the photometer screen a Rubens thermopile connected to a sensitive galvanometer. Preliminary calibration with a rotating sectored disc enabled galvanometer deflections to be accurately interpreted in terms of radiant energy.

[1] PHYS. REV., Vol. 17, p. 371.

The selective reflection of the silvered mirror M was corrected for according to the factors determined by L. R. Ingersol (*loc. cit.*); the correction in this case amounting to $1\frac{2}{3}$ per cent. of the result. To correct for the absorption of the fluorite window F, the efficiency of a Nernst glower was determined with and without the fluorite in the path of the undispersed radiation; from which it was found that an increase of 7.8 per cent. of the observed efficiency was necessary. This method of determining the correcting factor of course involves the assumption that the percentage absorption of the plate is substantially the same for the carbon radiation as for that from the Nernst glower which is at a considerably higher temperature. Since it is only a correction which is being determined, however, the error introduced in this way is probably negligible.

As is usual, the visible spectrum was assumed to end at the A line — and in accordance with this the adjustment of the diaphragm at C which cut off the infra red region, was frequently tested.

The results obtained for different power consumptions are as follows:

Watts Input.	Observed Efficiency.	Corrected Efficiency.	Watts Input.	Observed Efficiency.	Corrected Efficiency.
61	2.17 %	2.38 %	75.5	2.41 %	2.63 %
65.5	2.18	2.39	78.0	2.47	2.70
70.5	2.24	2.45	81.5	2.68	2.93
70.75	2.26	2.47			

By eye comparison with an incandescent lamp it was possible to identify with fair accuracy normal brilliancy as that corresponding to about 75 watts input, for which the efficiency is about 2.6 per cent. By means of the accompanying curve of luminous efficiencies as a function of temperature, computed from Wien's Law, for a "black body" it is found that the "black body temperature" of the normal filament is about 2150° absolute; which is undoubtedly somewhat higher than its actual temperature on account of its selective emission.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF WISCONSIN,
December, 1904.

CIRCULAR DICHROISM IN NATURAL ROTARY SOLUTIONS.

By M. F. McDowell.

THE anomalous rotation of the plane of polarization in active solutions is a well known phenomenon. But circular dichroism or the unequal absorption of two circular components of a plane polarized beam of light was first studied by Cotton,[1] to whom it was suggested from analogy with dichroism in double refracting crystals. He found several solutions which gave anomalous rotation but was able to detect circular dichroism in but two, potassium chromium tartrate and copper tartrate dissolved in NaOH and KOH. He also dissolved chrome alum in sodium, potassium and ammonium tartrate, which forms the same compound as potassium tartrate with potassium bichromate, and the curves obtained with the chrome alum solution were similar in form to those obtained with the potassium bichromate in potassium tartrate, the amount of the elliptical effect depending upon the relative amount of the alum and the sodium, potassium or ammonium tartrate.

The object of the present investigation is: first, to study the above solutions in all parts of the spectrum; second, to study some solutions in which Cotton failed to find the effect; third, to study some solutions which Cotton did not investigate.

The method used, which will be described later, made it possible to take readings in any part of the spectrum and to establish beyond a doubt the form of the curves within the absorption band of all the solutions studied where the absorption band was within the visible spectrum. The phenomenon of circular dichroism was found in every case where there was any marked anomalous rotation. The only condition seems to be that we have a double salt formed by the combination of an optically active acid or its salt and the salt of some other acid. For instance, when Cotton mixed two concen-

[1] Ann. de Chem. et de Phys., Series 7, tome 8, p. 347.

trated solutions, one containing 0.75 gram of potassium dichromate and the other 10 grams of potassium tartrate, he observed that the solution changed gradually to a dark brown, then to a green and, on evaporation, there were deposited dark green crystals which, gave an anomalous absorbing solution when dissolved in water. The writer has repeated his work and has duplicated it with potassic cobalt tartrate. When we mix two solutions containing, the one cobalt chloride and the other potassium tartrate or Rochelle salts, and then heat the solution to the boiling point for some minutes and allow it to stand, it changes from a reddish to a reddish brown and then to a rich wine color, and if exposed to the air will deposit wine colored crystals which, when dissolved in a dilute solution of ammonia, give circular dichroism.

The method used by Cotton for measuring both elliptical polarization and rotation was by means of spectral bands and, since the ellipticity is the greatest near the region of absorption, it required the selection of a biquartz plate which gave a band in or near this region. This was not always easy to do and after the plate had been selected the greater difficulty still remained; that is, the difficulty of detecting the shift of a dark band in the region of absorption. Both the solution and the biplate tend to cut out the light and as a consequence the field becomes very dark. Again Cotton claimed a sensibility, under favorable conditions, which enabled him to detect a difference in absorption of 1/1,000. It will be seen that by the method employed here, a difference of 1/10,000 can easily be detected, and under favorable conditions much less, say one part in 14,000 or 15,000 while the light is not reduced at the point of observation.

The system employed in this work was the Brace Half-Shade Elliptical Polarizer and Compensator.[1] It consists essentially of a thin strip of mica of an order of about 1/90, covering half of the field and another strip of about twice that order covering all of the field, and both placed between the polarizing and analyzing nicols. To detect elliptically polarized light, the two nicols are crossed making the field completely dark. Then the strip covering half of the field is introduced and turned so that the principal plane of the mica is

[1] PHYSICAL REVIEW, February, 1904, Vol. XVIII., and September, 1904, Vol. XIX.

at an angle of 45° to the plane of polarization. This causes that half of the field to lighten up more or less depending upon the order of the strip. Now introduce the compensator and turn it into such position that the two halves of the field are of the same intensity, in which case the line of the strip vanishes almost completely, making the conditions for comparison almost ideal. If now the body producing ellipticity is placed anywhere in the field between the two nicols, one half of the field darkens and the other half lightens up. To get a match, the compensator is rotated to the right or to the left until the field is again uniform. The number of degrees of rotation is read on a divided circle and when the order of the compensator is known the relative absorption of one circular component over the other may be calculated.

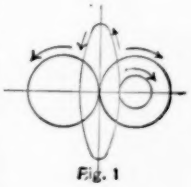
Fig. 1

Graphically it may be obtained as follows. Let the two circles, Fig. 1, represent the resolution of the linear vibration into its opposite circular components. If now one, that is represented by the dotted line, be absorbed the resultant is the ellipse whose major axis is the sum of the two diameters and whose minor axis is the difference of the two diameters. Thus for the two full line circles we have the ellipse shown, and the opposite if the other circle is absorbed most.

Fig. 2

If r and l, Fig. 2, are the diameters of the two circles, $r-l$ and $r+l$ are the minor and the major axes of the ellipse. Then $\tan\varphi=(r-l)/(r+l)$. When $r=l$, $\tan\varphi=0$, that is there would be no absorption and therefore no elliptical effect. If now in measuring the ellipticity a one-fourth wave-plate is used the tangent of the angle measured on the divided circle would be $(r-l)/(r+l)$. In practice, however, a one-fourth wave-plate is much too thick, as explained above, and the angle read on a circle is larger than φ in the ratio of

$$\frac{\frac{1}{4}}{\frac{1}{x}}=\frac{x}{4}$$

where $1/x$ is the order of the plate used. In terms of the compensator used here it would be

$$\frac{\frac{1}{4}}{\frac{1}{40}} = \frac{40}{4} = 10,$$

i. e., the angle measured is ten times larger than the φ explained above.

This does not yet give the ratio of the intensities or $(r/l)^2$. Since

$$\tan \varphi = \frac{r - l}{r + l}$$

we have

$$\frac{r}{l} = \frac{1 + \tan \varphi}{1 - \tan \varphi} = \tan (45^\circ + \varphi)$$

and

$$\frac{r^2}{l^2} = \frac{(1 + \tan \varphi)^2}{(1 - \tan \varphi)^2} = \tan^2 (45^\circ + \varphi).$$

If φ is very small, as in the cases here studied, we have

$$\frac{r^2 - l^2}{l^2} = \frac{4 \tan \varphi}{(1 - \tan \varphi)^2} \text{ or } \frac{I}{I_l} = 4\varphi,$$

which give the relative absorption of the two components.

The order, 1/40, of the compensator used in the following measurements was for the yellow green rays. Rotating the compensator through 0°.1 would give a marked change in the two halves of the field in any part of the spectrum. This would correspond to a difference in phase of $\lambda(0.1/45 \times 1/40)$ or $\lambda/18{,}000$. This degree of accuracy could not be realized in the present work because of errors of the system which enter in when the medium studied rotates the plane of polarization.[1] To get a match when the region gives both rotation and ellipticity it is necessary to rotate the analyzing nicol until the field is of minimum intensity and then rotate the compensator until a match is secured. Such were the conditions in the present work. For each wave-length a series of from six to ten readings were taken and the analyzing nicol was set for each reading. It was found that the extremes varied about 0°.5, or 0°.25 from the mean. This still gives a sensibility of $\lambda/7{,}200$ which is about seven times that claimed by Cotton. A

[1] Brace, PHYSICAL REVIEW, September, 1904.

glance at the results will show that in every case the error is small in comparison with the effect.

The accompanying diagram, Fig. 3, shows the arrangement of the apparatus. A beam of sunlight reflected from the mirror of a heliostat falls upon the condensing lens, L, and is brought to a focus at the strip S after reflection from the mirror M. The diverging beam falls upon the achromatic lens l placed at the focal distance of S. The parallel beam of light is dispersed by two prisms p, p, which are pivoted at the outer corner of the base of each and the angle between them can thus be varied at will by a micrometer screw ms, thus shifting the spectrum across the slit s'. Another achromatic lens l' brings the light to a focus on the slit s'. The

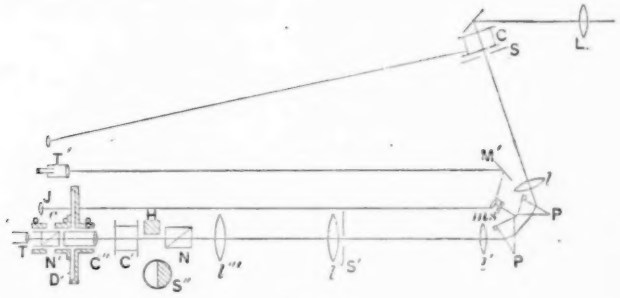

Fig. 3.

lens l'' is introduced to recombine the colors. The lens l''' is placed in such a position that the image of the slit s' is found in the focal plane of the telescope T. n and n' are the polarizer and the analyzer respectively. H is a Lippich "half-shade" plane polarizer used to measure the rotation of the plane of polarization. S'' and C'' are the strip and compensator. H is removed and S'' is introduced in its place and C'' is clamped to the divided circle d. n' is clamped to the stationery support, e, when C'' is used. m' is a mirror and T' is a reading telescope used in reading the divisions of the micrometer screw head ms, by means of which the wave length used is determined, the micrometer screw first being calibrated in terms of the Fräunhofer lines. C and C' are two cells of the same length which contain the solution examined. C is thrown into the field when the first setting is made to determine the zero

reading of the circle. When C' is thrown into the field C is removed; thus the distribution of the light intensity in the field is kept constant.

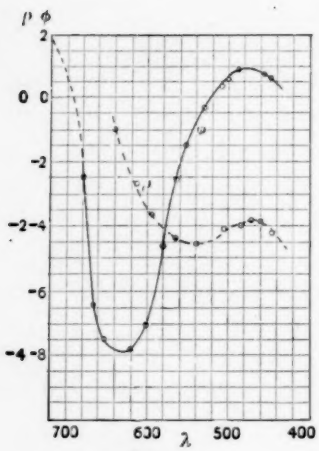

Fig. 4.

The following results are means of from six to ten readings, more readings being taken where a match was most difficult to obtain. In taking measurements, the ellipticity was measured in all parts of the spectrum. Then the strip and compensator were removed and the Lippich "half-shade" introduced and the rotation measured, using the same solution in the same cell. λ is expressed in $\mu\mu$. In the following tables ρ is the rotation of the plane of polarization and φ is the number of degrees of rotation of the compensator necessary for a match. In Fig. 4, A is the thickness of the cell in mm. that will transmit ten per cent. of light.

Fig. 4. — Continuous curves. Potassium chromium tartrate formed by adding .5 gm. of potassium bichromate to 100 c.c. of concentrated solution of neutral potassium tartrate. Length of cell, 1 cm.

λ.	690	685	667	658	636	628	615	596	580	574	566
φ.	—0.7	—1.0	—0.5	—0.35	—0.5	1.3	3.7	8.05	12.0	12.4	12.4

λ.	558	550	540	520	500	492	485	476	472
φ.	11.9	10.4	8.8	3.8	0.7	000	—0.4	—1.0	—0.7

λ.	700	682	667	655	644	615	600	580	562	536	517	500	492
ρ.	—0.1	—0.2	—0.35	—0.4	—0.7	—1.46	—1.9	—1.0	0.8	1.9	2.4	2.3	2.0

The dotted curve is plotted from the following data obtained with the same solution as above, concentration 1.5 gm. of potassium bichromate to 100 c.c., length of the cell, 3.3 mm.

λ.	672	650	618	598	578	560	531	518	505	496	485	467
φ.	0.6	1.3	2.0	4.0	5.0	5.7	4.7	3.5	1.6	1.3	0.6	—0.2

In this case the amount of potassium bichromate in 100 c.c. was three times that of the above, while the length of the cell contain-

ing the solution was reduced to one third. A glance at the curve will show that the elliptical effect is displaced and only about one half the former. This would indicate that not all the bichromate was active in forming the double salt.

The curve of transmission, furnished by Professor B. E. Moore, is given with the above data showing the relation between the ellipticity and the absorption band. A glance will show that the greatest effect is within the region of the greatest absorption.

In plotting the curves in this plate, to locate any value of φ, ρ or A for a given value of λ one must go along the λ scale to the proper wave-length, then follow the line of abscissæ until it intersects the dispersion curve. From the point of intersection follow the ordinate to the given value of φ, ρ or A.

Plate II. — Copper tartrate, 2 gm. in a solution of sodium hydroxide, 2 gm. to the 100 c.c. Length of cell, 3.3 mm.

λ.	680	669	656	620	602	581	566	555	532	510	500
ϕ.	−2.5	−6.4	−7.5	−7.8	−7.0	−4.6	−2.6	−1.5	−0.3	+0.4	+0.6
λ.	490	477	450								
ϕ.	+0.9	+0.7	0.6								

λ.	640	614	592	568	540	507	485	470	460	452
ρ.	−0.5	−1.3	−1.8	−2.2	−2.3	−2.1	−2.0	−1.9	−1.95	−2.2

Plate III. — Cobalt tartrate in dilute solution of ammonia, .5 gm. to 100 c.c. Length of cell, 3.3 mm.

λ.	665	620	592	570	555	535	505	493	478
ϕ.	1.2	0.7	0.7	1.2	3.0	5.2	4.4	3.6	2.8

λ.	660	620	600	580	570	540	510	480
ρ.	000	0.4	0.5	0.7	0.8	0.75	0.7	0.7

Plate IV. — Curve A. Malate of copper, prepared by saturating cold-water solution of malic acid with copper hydroxide and evaporating at 40°.0, and dissolving the residue in water. Length of cell, 1 cm.

λ.	620	610	600	593	585	570	525	500	480
φ.	3.0	2.55	2.00	1.5	1.3	0.8	0.2	000	000

λ.	635	620	596	562	542	500	480
ρ.	0.6	0.8	0.7	0.6	0.6	0.6	0.6

Plate IV. — Curve B. Nickel tartrate, prepared by dissolving 2 gm. of nickel carbonate in 100 c.c. of concentrated solution of cream of tartar. Length of cell 4 cm.

λ.	625	602	579	545	507	480	468	450
ϕ.	2.0	1.9	1.9	1.5	1.2	0.1	1.5	1.6
λ.	642	620	547	525	493	477	460	442
ρ.	0.6	0.64	0.9	0.96	1.1	1.2	1.3	1.36

A glance at the transmission curve in Plate I. will show that there are two absorption regions for this solution. One in the yellow green between $\lambda = 550$ and $\lambda = 590$ and another in the violet beyond $\lambda = 450$. The first one corresponds exactly with the point of greatest effect in the curve of ellipticity. The second one is beyond the limits of observation with the apparatus used.

The curve of rotation, ρ, has the maximum negative value in the edge of the band and decreases rapidly becoming zero in the middle of the band and then increases rapidly on the positive side until it reaches the other limits of the band where it continues almost horizontally at about 2°.0 or 2°.5.

In the case of copper tartrate, Plate II., the curves would indicate only one absorption band, unless the second should be out in the extreme violet beyond $\lambda = 400$. The band is between $\lambda = 600$ and $\lambda = 660$ where the ellipticity has a maximum negative value. The curve of rotation has a value 0° in the center of the band and increases negatively to about $-4°.6$ where it remains with small fluctuations through the rest of the spectrum. It can be seen that both curves tend to increase negatively at about $\lambda = 450$, which was the limit of observation.

Copper malate, Plate IV., Curve A, absorbs the entire red end of the spectrum and it was impossible to get readings beyond $\lambda = 620$ or $\lambda = 630$. Beginning at the violet end of the spectrum the curve of ellipticity has a 0° value at about $\lambda = 500$ and increases rapidly up to $\lambda = 620$ which was the limit of observation. At this point the curve of rotation has a maximum value. One point further in the red was taken which shows a decrease and a continuation of the curve crosses the zero line at about $\lambda = 670$ which point is probably in the middle of the absorption band.

Nickel tartrate, Curve B, Plate IV., also absorbs the red end of the spectrum beyond $\lambda = 630$. The rotation increases gradually across the spectrum from $\lambda = 640$ to $\lambda = 440$. A continuation of the curve would cross the zero line somewhere in the infra-red. The

ERRATA.

IN the article entitled "Circular Dichroism in Natural Rotary Solutions," by M. F. McDowell (Vol. XX., p. 163), three plates of curves were unfortunately omitted. These plates, together with one plate, which appears on p. 168 as Fig. 4, are given below.

On p. 168, line 18, for Fig. 4, read Plate I.

On p. 168, line 21, for Fig. 4, read Plate I.

In the plates ρ is the rotation of the plane of polarization and φ is the number of degrees of rotation of the compensator necessary for a match. In Plate I., A is the thickness of the cell in mm. that will transmit ten per cent. of light.

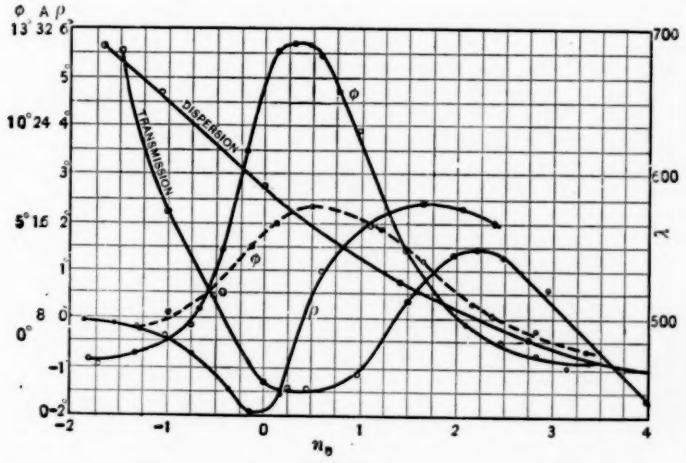

Plate I.

Plate I.—Continuous curves. Potassium chromium tartrate formed by adding .5 gm. of potassium bichromate to 100 c.c. of concentrated solution of neutral potassium tartrate. Length of cell, 1 cm.

The dotted curve is plotted from the data obtained with the same solution as above, concentration 1.5 gm. of potassium bichromate to 100 c.c., length of the cell, 3.3 mm.

In this case the amount of potassium bichromate in 100 c.c. was three times that of the above, while the length of the cell containing the solution was reduced to one third. A glance at the curve

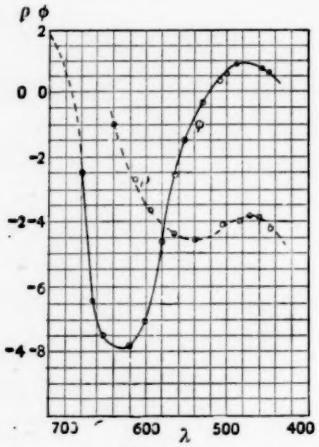

Plate II.

will show that the elliptical effect is displaced, and only about one half the former. This would indicate that not all the bichromate was active in forming the double salt.

The curve of transmission, furnished by Professor B. E. Moore,

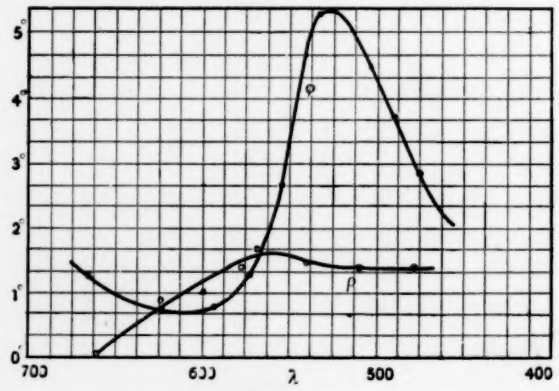

Plate III.

is given with the above data showing the relation between the ellipticity and the absorption band. A glance will show that the greatest effect is within the region of the greatest absorption.

In plotting the curves in this plate, to locate any value of φ, ρ or A for a given value of λ one must go along the λ scale to the proper wave-length, then follow the line of abscissæ until it intersects the dispersion curve. From the point of intersection, follow the ordinate to the given value of φ, ρ or A.

Plate II. — Copper tartrate, 2 gm. in a solution of sodium hydroxide, 2 gm. to the 100 c.c. Length of cell, 3.3 mm.

Plate III. — Cobalt tartrate in dilute solution of ammonia, .5 gm. to 100 c.c. Length of cell, 3.3 mm.

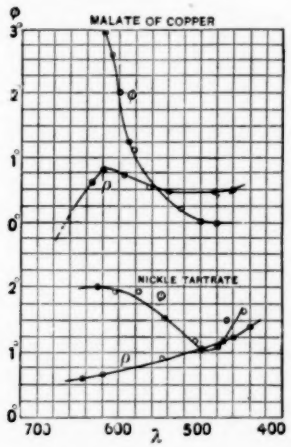

Plate IV.

Plate IV. — Curve A. Malate of copper, prepared by saturating cold-water solution of malic acid with copper hydroxide and evaporating at 40°.0, and dissolving the residue in water. Length of cell, 1 cm.

Plate IV. — Curve B. Nickel tartrate, prepared by dissolving 2 gm. of nickel carbonate in 100 c.c. of concentrated solution of cream of tartar. Length of cell 4 cm.

rotation in all cases is small owing to the dilution of the solution and the shortness of the containing cell.

The writer is indebted to Dr. D. B. Brace, Professor of Physics in the University of Nebraska, in whose laboratory and under whose direction this work was done, for his kindly assistance and suggestions which made the carrying on of this work possible.

DEPARTMENT OF PHYSICS, MORNINGSIDE COLLEGE,
SIOUX CITY, IOWA.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE TWENTY-SEVENTH MEETING.

A REGULAR meeting of the Physical Society was held in Fayerweather Hall, Columbia University, New York City, on Saturday, February 25, 1905. President Barus presided.

The following papers were presented:

1. Color in Platinum Films, Isabelle Stone.

2. On the Properties of Magnets Made of Hardened Cast Iron,[1] B. O. Peirce.

3. The numbers and gradations in size of the nuclei of dust-free air energized, or not, by X-rays or other radiation, with remarks on the physical structure of air, Carl Barus.

4. Note on the condensation phenomena of the enclosed steam jet, with their bearing on the physical structure of dust-free air, Carl Barus.

5. Application of the Electron Theory, C. B. Thwing.

6. The Effect of Pressure upon the Resistance of Selenium Cells,[2] F. C. Brown. Presented by A. P. Carman.

On motion the Council was requested to consider a plan for holding an informal dinner in connection with the meetings of the Society.

Adjourned.

ERNEST MERRITT,
Secretary.

THE SPECIFIC HEAT OF AIR AT LOW TEMPERATURES.

BY J. S. SHEARER AND R. C. FENNER.

A DETERMINATION of the mean specific heat at constant pressure of air from 18° C. to — 160° C. was made by Witkowski,[3] using air compressed in cylinders, cooled, and then passed through a calorimeter. The curve of cooling for the calorimeter was taken just before passing in the air also during and after the flow. The difficulties in this method are obvious and a constant temperature method was sought in order to eliminate one great source of trouble.

A careful series of determinations of the heat of vaporization of air by Messrs. Fenner and Richtmyer has shown that for a considerable range

[1] Read by title.

[2] Read in abstract by the secretary.

[3] Phil. Mag., 1896, 42, 1.

of variation in composition the heat of vaporization is very nearly constant. Liquid air may be vaporized by the energy from a current of air instead of an electric current and the mean specific heat thus determined. Air at room temperature was passed from a compression cylinder through a coil of copper tubing immersed in liquid air in a Dewar bulb. The amount of air passed through the coil and the amount vaporized was measured by two gas meters and the temperature drop was observed by means of a steel constanton thermo couple. In order to make the evaporation by causes other than the air current as small as possible thin glass tubes were used to carry the air through the stopper and these were joined to the metal tube below the surface of the liquid. These lead tubes were jacketed and the thermo junction were placed as close as possible to the surface of the liquid. The thermal E.M.F. was measured by the potentiometer method, using a cadmium cell and a sensitive galvanometer. The flow of gas was controlled by a needle valve and the spot of light from the galvanometer mirror could be kept at zero for several minutes without changing the air current.

The meters were read by taking flash-light photographs during and between the runs so that correction could be made for the loss rate due to conduction.

Owing to lack of time the results have not been worked up fully as yet but it is evident that no material change in the specific heat of air is to be expected for a range of 180°. The following values are subject to slight correction when the thermo-element and loss rate have been studied more in detail.

Run No. 1	Range of temperature	178°	specific heat .2220
" " 2	" "	182°	" " .2301
" " 3	" "	180°	" " .2340
" " 4	" "	184°	" " .2222
	Regnault's value	18°	.2374
Witkowski	20° to	98°	.2372
	16° "	— 77°	.2374
	17° "	—102°	.2372
	18° "	—170°	.2427

A Direct Measurement of the Thomson Thermoelectric Coefficient in Soft Iron.[1]

By E. H. Hall.

THIS coefficient is the factor by which the absolute temperature of the metal at any section must be multiplied in order to find the amount of heat reversibly generated or absorbed per second by one

[1] Abstract of a paper presented at the meeting of the Physical Society and of Section B of the American Association for the Advancement of Science of Philadelphia, December 28, 1904.

ampere flowing at the section considered between points differing from each other one centigrade degree in temperature.

Attempts at direct measurements of this coefficient in any metals have been few, as the Thomson effect is small and difficult to measure. Battelli, who was perhaps the only one before Professor Hall to attempt this measurement with iron, got for the coefficient the value 32×10^{-9}. Professor Hall finds the value 76×10^{-9}, more than twice as great as the number found by Battelli. Professor Hall's method was to place two similar iron rods, each about 20 cm. long and 1 cm. in diameter in the part studied, side by side, with one end of each rod in ice water and the other end of each in boiling water, and to send a strong electric current, 25 amperes, from cold to hot in one bar and from hot to cold in the other bar. With this arrangement, which is similar to that used by other investigators of the Thomson effect, the current generated more heat in one bar than in the other bar, and this made the slope of temperature different in the two bars. The difference of temperature slope at different parts of the two bars was measured by means of thermoelectric couples consisting of fine wires of copper and german-silver joined together at their ends and wound on the bars. With such a device and with a sensitive galvanometer it is not difficult to detect one five-thousandth part of a centigrade degree of temperature. From the differences of temperature slope thus found, taken with the electrical and thermal conductivities of the iron, the Thomson effect coefficient defined above was calculated.

Such investigations have an important bearing on the interesting question of the way in which heat is converted into electrical energy in the thermoelectric current. This question was the subject of Professor Hall's vice-presidential address before Section B of the association on December 29, 1904.

NOTE ON THE USE OF SENSITIVE QUADRANT ELECTROMETERS.[1]

BY J. C. MCLENNAN.

IN making measurements upon the conductivity of a gas by means of a highly sensitive electrometer such as the Dolezeleck type of instrument the writer has frequently experienced considerable delay and inconvenience on account of the disturbance imparted to the needle by simply breaking the earth connection to the free quadrants. Even comparatively small oscillations imparted to the needle in this way require from half a minute to three or four minutes to subside and this period though not long is still often quite sufficient to prevent observa-

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society on December 30, 1904.

tions upon the conductivity of a gas under specially interesting circumstances.

For example in studying the decay of activity induced in a body by exposure under negative electrification to the emanation from radium, thorium or other similarly active substances, it is highly desirable to make observations on the intensity of activity as soon as possible after the exposure has ceased and as any initial oscillations set up in the needle on breaking the earth connection must necessarily delay these until the initial stages of the decay of activity are past, it is most desirable to take every precaution to eliminate the disturbances as far as possible.

Such disturbances are in great measure due, as many experimenters have noticed, to electrostatic effects caused by the approach of the observer's body or even his hand in the process of breaking the earth connection and in order to avoid them it has become the practice to surround the electrometer and the testing apparatus with earth-connected metallic screens, and also to make and break the earth connection to the quadrant by keys of a special form which the observer can operate from a distance by means of strings or other connections. In using the different keys, however, which have come to his notice the writer found that with electrometers of high sensitiveness, small though relatively important initial disturbances still existed and arose from a variation in the capacity of the measuring system caused by the action of the key itself when the earth connection was broken. In order to overcome this defect it was only necessary to take special precautions in the construction of the key to reduce this variation in capacity to a minimum.

With the modifications which are described below it was found possible when all parts of the apparatus were well screened to break the earth connection to the quadrants without any observable oscillations being set up in the needle. As a consequence measurements could be made upon the conductivity of a gas at any instant with the greatest possible accuracy.

The general arrangement of apparatus adopted by the writer in measuring the conductivity of a gas is shown in Fig. 1. The receiver *A*

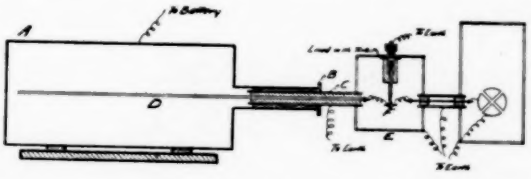

Fig. 1.

which contains the gas whose conductivity is to be measured rests on insulating supports and is connected to a battery of small storage cells.

It is provided with an ebonite plug B, which carries an earth connected brass tube C. This tube in turn also carries a second ebonite plug which supports the exploring electrode D. The tube C and the electrode D penetrate a small wooden box E lined with tin foil also connected to earth and connection is made at F with the contact key of special form. The electrometer is supported in a box of wood lined with tin foil connected to earth and its free quadrants are connected to the key F by a wire supported by ebonite plugs in an earth-connected brass tube which at one end penetrates the box containing the key and at the other that containing the electrometer.

The key of special form is shown in Fig. 2 and consists of two brass parts A and B held by means of the ebonite support C with their parallel faces as close together as possible without touching. The whole is supported against the tin foil lining on the top of the box by the nut E and this, of course, keeps the upper part A always connected to earth. Both parts A and B as shown in the figure are pierced by a small opening lesss than a millimeter in diameter and the earth connection to the quadrants is made or broken by inserting or withdrawing a fine rigid steel wire D, which moves freely through this opening. The wire D may be tipped with platinum if desired, but in practice, this precaution was not found necessary. It will be readily seen that with this device the earth connection can be broken with practically no variation in the capacity of the measuring system. By using this key and making the arrangements described above for screening off electrostatic induction it has been found quite immaterial whether the earth connection is broken by hand or by means of strings operated from a distance. In either case the process is not followed by any disturbance of the needle. All initial oscillations are entirely eliminated and the needle although starting from rest at the moment the contact is broken almost immediately assumes a steady rate and its motion may be taken as a measure of the conductivity of the gas at the instant the quadrants are freed.

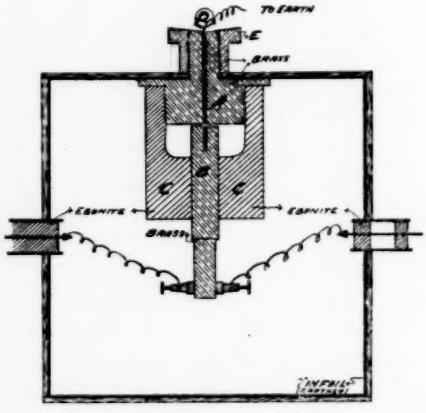

Fig. 2.

On the Decay of Excited Radioactivity from Natural Gases.[1]

By Miss L. B. Johnson.

In a recent paper by Professor J. C. McLennan "On the Radioactivity of Mineral Oils and Natural Gases"[2] it was shown that the natural gases of Ontario contain an emanation which is similar to that found by other investigators in the gases contained in certain spring waters and in the air drawn from the surface layers of the earth, and which, from its rate of decay as well as that of the radioactivity excited in bodies exposed to it, bears a strong resemblance to the emanation from radium.

In a paper by Miss Brooks[3] the results are presented of a series of measurements on the radiation from rods rendered radioactive by exposure to the emanation from thorium, radium and actinium. In this paper it is shown that, in the case of rods exposed for short periods to the emanation from thorium the radiation at first increases, reaching a maximum in about two hours after removal, and then decays according to an exponential law. A similar result was obtained with rods exposed to the emanation from actinium, the only difference being that the maximum intensity with this substance is reached in about ten minutes after removal. But when the rods were exposed to the emanation from radium, it was found for all exposures that there was a rapid initial decrease in the intensity of the radiation for the first ten minutes; after which it remained constant for a length of time which decreased with the increase in the period of the exposure; then it dropped gradually and approached a zero value.

From these results it is evident that activities excited in rods by exposure to radium, actinium or thorium have certain characteristics by which they may be definitely distinguished.

The experiments described in this paper were carried out in order to examine more closely the emanation found in the natural gases mentioned above, and to throw further light on the question whether the radioactivity was due to the presence of the emanation from radium or due to the materials themselves possessing the intrinsic property of radioactivity The behavior of the emanation was studied and a series of curves obtained showing the decay of the radiation due to the excited activity on rods exposed for different periods in the gas. It was found for all exposures that the activity dropped at first and reached a steady state which lengthened as the period of exposure was shortened. It then gradually died down to and approached a zero value. These curves are very similar to

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society on December 30, 1904.

[2] Paper presented at International Electrical Congress at St. Louis, September, 1904.

[3] Philosophical Magazine, September, 1904.

those given by Miss Brooks for rods exposed to the emanation from radium and, therefore, support the theory that the emanation found in the natural gases dealt with is due to the presence of radium at their source. Moreover, Professor Rutherford in his work on "Radioactivity"[1] gives results showing that the amount of activity excited on a rod exposed to the emanation from radium is always directly proportional to the amount of emanation present. To see if this was true of the active emanation in natural gases, exposures of the same period were made in the same gas on different days and it was found that, as the activity of the emanation decreased, there was always a proportionate decrease in the amount of activity which it excited.

The gas under investigation was confined in a cylinder about 60 cm. long and 25 cm. in diameter. Brass rods were suspended in the gas by insulating supports, and connected to the negative terminal of a Toepler-Holtz machine, which maintained a potential of 11,000 volts. After exposure the rods were inserted in a second receiver of the same size through which a gentle current of air was drawn in order to remove any emanation adhering to them. Their activity was then determined by means of measurements upon the conductivity they imparted to the air in the receiver. These measurements were made with a sensitive Dolezeleck electrometer, and as the rods were directly exposed to the air, the conductivity imparted by them was due to all the types of rays which they emitted.

In the paper referred to above by Professor McLennan it was shown that when measurements were made upon the conductivity of the gas as it came from the well, it exhibited a steady decrease, and fell to one half

TABLE I.

Conductivity of Natural Gas.

Time.		Current.	Time.		Current.
Hours.	Minutes.	Arbitrary Scale.	Hours.	Minutes.	Arbitrary Scale.
	4	288	3	41	341
	7	292	4	10	340
	15	296	5	55	327
	21	301	12	45	310
	27	307	23	20	283
	44	313	47	25	215
1		320	71	15	172
1	31	331	95	15	135
1	40	335	119		104.5
2	46	340	145		78

[1] Rutherford, Radioactivity, page 274.

value in about 2.78 days. In the present investigation the gas was studied under slightly different circumstances. As soon as it was received from the well a rod was exposed in it at different times and under negative electrification for different periods. The rod in each exposure was rendered active by the deposit of the substance causing excited radioactivity, and it was always found that the removal of the active rod was followed by a rise in the conductivity of the gas to a maximum value, after which it gradually fell according to an experimental law in the same manner as before. A typical set of observations on this variation in the conductivity is given in Table I., and a curve representing them is shown in Fig. 1.

In this case a negatively charged rod was exposed at 11,000 volts in the gas for ten hours, and it will be seen from the values given above that the conductivity steadily rose and reached a maximum value in about four hours after the removal of the negatively charged rod. It will also be seen that after the maximum value was reached the conductivity fell to one half value in about seventy hours.

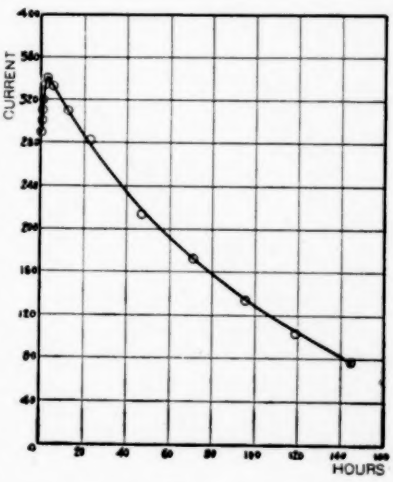

Fig. 1.

In order to investigate how the activity excited in a negatively charged rod varied with the time of exposure, a series of exposures for different periods was made on one day and the results of these observations are given in Table II. and curves illustrating them are shown in Fig. 2.

Before commencing this set of exposures a rod connected to the negative terminal of the electrical machine was suspended in the gas for about two hours. It was then withdrawn and the first exposure was made. During the intervals which elapsed between the different exposures, the electric field was always applied in the same manner to the gas, with the object of making the exposures in the presence of a freshly produced disintegration product.

The values given in Table II. and represented graphically in Fig. 2 show that for all periods of exposure the radiation decreased initially, then reached a steady state which lengthened as the period of the exposure decreased, after which it dropped steadily and approached a zero value.

TABLE II.

Two-minute Exposure.		Five-minute Exposure.		Ten-minute Exposure.		Twenty-minute Exposure.	
Time in Minutes.	Current Arbitrary Scale.	Time in Minutes.	Current Arbitrary Scale.	Time in Minutes.	Current Arbitrary Scale.	Time in Minutes.	Current Arbitrary Scale.
1	25.0	1	48.9	1	61.0	1	79.5
2	18.0	6	28.0	2	55.0	2	71.5
7	9.5	11	19.9	6	39.5	5	56.5
11.5	7.0	16	19.3	11	32.5	6	51.5
16.5	4.5	21	17.2	15	29.0	11	49.5
21.5	4.0	31	16.2	25	31.0	16	51.0
26.5	5.0	36	14.9	31	30.0	21	50.5
31	4.0	46	12.0	37	31.5	26	49.0
36	5.0	51	11.7	41	30.0	30	50.0
41	4.5	56	11.6	45	29.0	36	44.0
46	3.5	61	9.7	51	24.0	40	44.5
51	3.5			56	23.0	46	44.5
61	3.5			61	21.0	51	39.5
						56	36.5
						61	35.5
Forty-minute Exposure.		One-hour Exposure.		Two-hour Exposure.		Four-hour Exposure.	
1	125.0	4	154.3	1	196.7	1	252.3
2	122.0	7	141.3	5	174.7	4	218.3
6	102.5	11	130.8	6	173.7	17	184.3
11	96.0	20	128.8	11	163.2	35	152.3
16	91.5	25	126.3	16	154.2	42	137.3
21	93.0	30	120.3	26	148.2	52	124.3
26	90.0	35	116.3	31	141.7	60	108.0
36	82.5	40	105.8	36	134.2	65	95.3
41	76.0	45	100.8	41	126.7	69	89.5
46	73.5	50	90.8	46	113.2		
52	66.5	55	83.3	51	108.7		
56	61.0	60	78.3	56	91.7		
61	56.5			61	92.7		

These curves on account of their similarity to those of Miss Brooks for exposure in the emanation of radium form another link in the chain of evidence which leads to the conclusion that the emanation found in natural gases has radium for its source.

As stated above the results given in Table II. were obtained from observations made in one day upon the same gas. During this period as Fig. 1 shows, there was a gradual decay of the emanation. To determine the relation existing between excited radioactivity and the strength of the emanation producing it a series of exposures of five minutes duration was made on three succesive days in the same gas.

In making these measurements the conductivity of the gas was first determined, an electric field then applied as before and the exposure

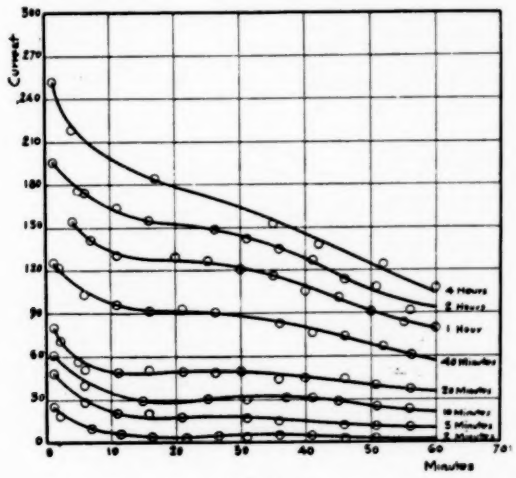

Fig. 2.

made in the gas thus treated. The same procedure was followed on each day so as to maintain as far as possible the same conditions. The results of these observations are given in Table III. which contains a record of the decay of the activity excited on each of the days.

TABLE III.

Excited Radioactivity (Five-minute Exposures).

Column I. (First Day).		Column II. (Second Day).		Column III. (Third Day).	
Time in Minutes.	Current (Arbitrary Scale).	Time in Minutes.	Current (Arbitrary Scale).	Time in Minutes.	Current (Arbitrary Scale).
1.52	110.2	1.5	90	1.5	64.5
4	70.2	9	40	2.5	55.5
5	67.2	10	32	10	24.5
10	40.2	15	30	15	27.5
15	37.2	20	35	20	28
20	38.7	24	34	25	28.5
25	39.2	30	35.6	30	28.5
31	38.8	35	31.1	35	27.5
35	38.8	40	30.1	40	25.5
40	37.3	45	30.1	45	25
45	33.8	59	26.1	55	19
50	31.3	63	23.1	60	20
55	30.3				
60	31.8				

The strength of the emanation present in the gas on each day is given in Table IV.

TABLE IV.

Exposure.	Strength of Emanation.
First day	476
Second day	394
Third day	320

From an inspection of these values together with the results in Table III. it will be seen, that a direct proportionality exists between the strength of the emanation and the amount of activity excited.

TABLE V.

Excited Radioactivity (Five-minute Exposure).

Time in Minutes.	Column I. (First Day) Current.	Column II. (Second Day) Current.	Column III. (Third Day) Current.
1	110	108	94.8
10	40.2	38.4	36
20	38.7	42	41.1
35	38.8	37.3	40.4
40	37.3	36.1	37.4
45	33.8	36.1	36.7

Table V. contains a few of the results reduced on this basis. The values of the activity obtained in the first day are recorded in Column I. and the intensity of the emanation is assumed to be unity. Columns II. and III. contain the readings obtained on the second and third days corrected to an emanation of unit intensity. The general agreement of the values recorded in the three columns justify the assumption of the law of proportionality.

In the experiments described in this paper the effects found were produced by all the rays given off from the excited body. Experiments are now in progress to investigate these effects still further and especially to determine the decay curves on the basis of β and γ radiations.

ON THE SECONDARY RADIATION EXCITED IN DIFFERENT METALS BY THE γ RAYS FROM RADIUM.[1]

BY H. F. DAWES.

IN a recently published communication A. S. Eve[2] has shown that when β and γ rays from radium of constant intensity are allowed to fall upon different metals there is produced at the surface of the metal a

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society on December 30, 1904.

[2] Phil. Mag., December, 1904, p. 669.

secondary radiation consisting of β rays whose intensity varies with the different substances upon which the direct rays fall.

In the method adopted by Eve of measuring the intensity of these secondary rays, the radium was contained in a glass receptacle which was screened from a gold leaf electroscope by a thick block of lead. Plates of different metals were used as radiators and were so placed as to receive directly the exciting rays from the radium and at the same time permit the secondary rays emitted by the plates to fall upon a thin aluminium window in the side of the electroscope.

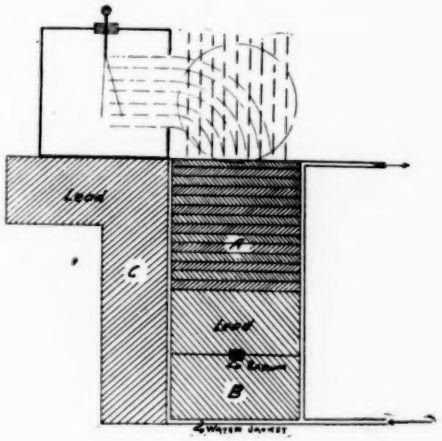

Fig. 1.

His results which were obtained with a long series of different materials go to show that the intensity of the secondary rays emitted was approximately proportional to the density of the material used as radiator.

In the following note the results are given of a series of experiments of a similar nature and as the method by which they were obtained is somewhat different from that of Eve they may be of interest as forming a supplement to his investigation. The method followed is illustrated in Fig. 1. A quantity of radium bromide (30 mg.) was placed at the center of a lead cylinder 6 cm. long and 6 cm. in diameter and over the cylinder there was placed a series of 13 plates of different substances. The whole, which was enclosed in a narrow water jacket so as to be kept at constant temperature was placed between the poles of a strong electromagnet with the uppermost plate in the center of the field.

A large block of lead about 3 cm. thick and of the shape indicated in the figure was closely fitted about the water jacket and upon this lead block was placed a gold leaf electroscope which was provided with a window of very thin aluminium foil on the side facing the pile of plates. With the exception of the platinum each of the plates was approximately 5 mm. in thickness, a size selected as being probably sufficient to cut off the secondary rays coming through a plate from the one below it. A magnetic field of 1,400 C.G.S. units was applied as shown by the circle in the figure so as to deflect the secondary rays issuing from the uppermost plate either towards the window of the electroscope or away from it.

In order to obtain a measure of the intensity of the secondary radiation emitted by the different substances each of the plates was in turn made the uppermost of the series and as the rays emitted by the radium always traversed the whole series the constancy of the exciting radiation

Rates of Discharge. (*Arbitrary Scale.*)

Radiator.	Column I.	Column II.	Column III.	Column IV.
	No Field.	Field On (1,400 C.G.S. Units).	Field Reversed.	Percentage Increase.
Lead	115	179.2	119.3	53.9
Platinum	123	186.7	126.5	50.1
Silver	115.8	166.9	118	42.5
Zinc	115.8	165.2	116	42.4
Tin	123.1	169.4	122.5	38
Aluminum	107.3	147.5	106.6	37.9
Antimony	112.2	157.4	117.3	37.9
Brass	107.8	154.4	118	37.1
Gold	114.2	154.1	118.1	36.3
Cadmium	120	163.4	120.6	35.9
Copper	111.1	150.7	114.5	33.5
Wood	117.2	153	113.2	32.9
Bismuth	113.9	149.9	114.7	31.5

was by this arrangement insured. The deflection of the gold leaf was observed by means of a microscope provided with a micrometer eyepiece and in making the measurements the rate of discharge of the electroscope was observed (1) without the application of a magnetic field, (2) with the field applied so as to deflect the secondary rays into the electroscope and (3) with the field reversed so as to deflect them away from it. Numbers representing rates of discharge under these circumstances are given in Columns I., II. and III, respectively, of the above table.

From these it will be seen that for any one radiator the number in Column I. differs but slightly from that given in Column III. which would seem to indicate that with no magnetic field applied very little of the secondary radiation from the uppermost plate penetrated the electroscope. This conclusion is confirmed by the fact that all the rates for the different metals under no magnetic field showed but little variation. The numbers given in Column II. show that the rate of discharge was greatly increased when the magnetic field was applied so as to deflect the secondary rays from the uppermost plate into the electroscope.

The rates given in Column I., represent the conductivity of the air in the electroscope due to the following causes (1) natural ionization, (2) the penetrating rays from the radium and (3) the secondary rays set up at the inner walls of the electroscope itself by the rays which penetrated

them and for the reasons given above the numbers in Column III. may be taken to represent the conductivity in the electroscope arising from the same causes. On the other hand the conductivity represented in Column II. is due, in addition to the above sources of ionization, to the secondary rays which were deflected by the magnetic field into the electroscope, and hence with each plate the increase in the rate of discharge in the second over that in the first or third series of the observations may be taken as a measure of the intensity of the secondary radiation which it contributed. In Column IV. this increase in the rate is stated as a percentage of the mean of the corresponding numbers in Columns I. and II. It will be seen from the readings of this column that while the secondary radiation from lead and platinum was high that from gold was relatively low. The intensity of the radiation from aluminium was also comparatively high and generally it would not appear from these results that the secondary radiation is even approximately proportional to the density of the substance used as radiator.

Magnetic fields ranging from 1,000 to 2,000 C.G.S. units were in turn applied with a number of the plates but no variation in the increased rate of discharge was observed from which it seemed evident that the field of 1,400 C.G.S. units was sufficient to deflect all the secondary rays.

Effect of Pressure on the Electrical Resistance of Selenium Cells.[1]

By Fay Cluff Brown.

With the idea of explaining the action of selenium when heated or illuminated, I have investigated the conductivity of several selenium cells under pressures as high as 600 atmospheres. In general the cells were made after the method of S. Bidwell.[2] Hydraulic pressure was obtained by use of a Caillettet pump with some improvements designed by Professor Carman. I give below one set of data for one cell, and a curve showing how the resistance varies with pressure.

Pressure $\frac{\text{k.gm.}}{\text{cm.}^2}$	Resistance Ohms.	Pressure $\frac{\text{k.gm.}}{\text{cm.}^2}$	Resistance Ohms.
218	63,900	70	84,400
150	72,510	50	87,800
120	76,980	30	91,150
100	79,790	0	96,000

[1] Abstract of a paper presented at the meeting of the Physical Society held on February 25, 1905.

[2] Phil. Mag., 1891, 250.

The cell was kept in a receiver which was packed in ice. The time necessary to reach the ice temperature after change of pressure was determined by separate experiment, so as to avoid temperature corrections.

From this curve and data one can see how definite and uniform is the effect of pressure. It is as remarkable as the effect of heat and light on the conductivity of the selenium cell.

Our work on selenium is still in progress. At a later date I shall given a complete report on the work and shall then discuss the elimination of the sources of error.

So far as I have been able to find out, in looking through Science Abstracts and the Beiblätter there has been no work done on the conductivity of selenium under pressure.

This work has been carried on under the direction of Professor A. P. Carman.

THE RELATION BETWEEN ELECTRICAL CONDUCTIVITY AND THE RATE OF GAS CONSUMPTION IN THE ORDINARY GAS FLAME.[1]

BY F. L. TUFTS.

THE investigations were carried on by the use of platinum electrodes, coated with calcium oxide, for the purpose of reducing the electrode resistances, and heated to incandescence by separate electrode flames. The flame, the conductivity of which was to be measured, was placed as a connecting flame between the two electrode flames. The conditions in the connecting flame could thus be varied without changing in any way the conditions about the electrodes. In the present investigations the burner used for the connecting flame had a narrow slot, 21 cm. long, cut in soapstone.

The investigations so far made upon the electrical conductivity of luminous and nonluminous gas flames seem to warrant the following conclusions:

The conductivity of the connecting flame is not altered by the introduction of small platinum wires which become heated to incandescence. In other words the presence of incandescent bodies does not appreciably increase the total amount of ionization in the flame.

Such wires when connected with an electrostatic voltmeter can be used to investigate the potential gradient in the connecting flame, and the gradient thus found is the gradient which exists in the flame when the voltmeter wires are not inserted.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society on December 30, 1904.

If the height of the connecting flame is uniform the gradient is found to be uniform between the two electrode flames.

The conductivity of a given cross-section of the flame, taken between faces perpendicular to the line joining the electrode flames, may be found by dividing the current, flowing between the electrode flames, by the potential difference between the two faces of the cross-section; the potential difference being found by inserting two wires connected to an electrostatic voltmeter, as described above.

The conductivity of a given cross-section, obtained in the above manner, has been found to vary directly as the quantity of gas consumed by the flame per second, so long as the character of the flame (luminous or non-luminous) remains the same, and the same burner is used.

The conductivity of the luminous flame is less than that of the non-luminous flame, consuming the same quantity of gas per second. With the burner used in these investigations it was found to be about two thirds as great.

When salt spray, from an atomizer containing a solution of the salt, is introduced into the flame, the conductivity imparted to the non-luminous flame is greater than the conductivity imparted to the luminous flame; the quantity of salt spray supplied to the flames being the same.

When acetylene gas was used with the same burner the conductivity of the non-luminous flame was found to be over two and a half times the conductivity of the luminous flame consuming the same quantity of gas per minute. For the same volume of gas consumed per minute, the conductivity of the non-luminous acetylene flame was found to be over three times the conductivity of the non-luminous gas flame consuming ordinary city gas. In both cases the conductivity was very nearly directly proportional to the volume of gas cousumed per minute.

Conductivity measurements were made upon a flame of pure hydrogen gas burned in the same burner. The conductivity of the pure hydrogen flame increased very much more rapidly than the volume of gas consumed. With a consumption of one tenth of a cubic foot per minute the conductivity was only about three and a half per cent. that of the non-luminous flame of illuminating gas, while with a consumption of five tenths of a cubic foot per minute the conductivity was over twenty-eight per cent. that of the non-luminous flame of illuminating gas, consuming the same volume per minute.

COLUMBIA UNIVERSITY.

THE ELIMINATION OF GAS ACTION IN EXPERIMENTS ON LIGHT PRESSURE.[1]

BY G. F. HULL.

WHEN light is thrown on one vane of a torsion system suspended in a partial vacuum, the "Crookes Effect" or gas action is eliminated, leaving only light pressure effective, in the following ways: (1) by making the vane accurately verticle; (2) by *enclosing* the absorbing or reflecting surface; (3) by making the vane a cylindrical surface having its axis coincident with the suspending fiber; (4) by using inclined surfaces and polarized light.

Experiments are described and data given showing that the gas action is eliminated through large ranges of air pressure varying from about half an atmosphere up to few millimeters of mercury.

A simple lecture room experiment is described for demonstrating that light pressure on a reflecting surface is greater than that on an absorbing surface in the ratio of $1 + r_1$ to $1 + r_2$ where r_1 and r_2 are the reflection coffiecients of the two surfaces.

THE MAGNETIC SUSCEPTIBILITY OF WATER.[1]

BY A. P. WILLS.

THE method employed in determining the magnetic susceptibility of water is quite similar to that which was used by the author some years ago in finding the susceptibility of solid substances. It is fully described in another place.[2] Briefly it consists in suspending from the arm of a sensitive balance a vessel containing water so that its lower edge is in a very strong magnetic field, and then measuring the mechanical force by means of the balance which the magnetic field exerts upon vessel and water; afterwards eliminating the effect of the vessel by repeating the procedure with the vessel empty which gives the data necessary to compute the action of the field upon the water alone.

The containing vessel was prismatic in shape, having inside dimensions 9.0 cm. × 3.65 cm. × .601 cm. the latter two, only, having to be accurately known. The long edge was vertical and perpendicular to the field, and the medium edge horizontal and perpendicular to the field.

The pole-pieces were separated by a distance of 1 cm. and their pole-faces were 6 cm. wide and 1 cm. high.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society on December 30, 1904.

[2] PHYS. REV., April, 1898.

The principal advantage of the method, apart from the facility with which it may be employed, lies in the accuracy with which the field strength of the magnet may be determined.

This was done by simply measuring with the balance the force on a conductor of known length, carrying a current of known strength, exerted by the field. The conductor was a strip of very thin tin foil pasted on the walls of the containing vessel. This is, I believe, by far the most accurate method known for measuring the strength of a magnetic field.

If A be the horizontal sectional area of the slab of water, P the mechanical force, k the coefficient of magnetic susceptibility of water, H the strength of the magnetic field at the bottom of the vessel, H_0 that at the top, all in C.G.S. measure, then

$$k = -\frac{2P}{A(H^2 - H_0^2)}.$$

H_0^2 was negligible in comparison with H^2; hence the working formula was

$$k = -\frac{2P}{AH^2}.$$

The following results were obtained at 18° C.:

H	$k \times 10^6$	H	$k \times 10^6$
4,190	−0.721	10,570	−0.718
5,620	−0.720	12,530	−0.724
7,430	−0.718	13,310	−0.718
8,890	−0.718	15,310	−0.724
9,520	−0.720		

The constancy of the coefficient with variable field thus appears to be verified.

NEW BOOKS.

Alternating Current Engineering Practically Treated. By E. B. RAYMOND. New York, D. Van Nostrand Co., 1904. Pp. 232.

This book is written by a member of the staff of the testing department of the General Electric Company; it consists of two parts: the first part contains the general theory of electricity and magnetism and a special theory of alternating currents; the second part treats of transformers, alternating current motors and alternators. In his preface the author states that his directing for many years in practical engineering of graduates from technical colleges, as well as young men starting in the electrical business without complete technical training, has impressed upon his mind the necessity for a general treatise on alternating-current engineering presented in a practical way without complex methods of explanation and free from any matters not bearing directly on purely engineering work. There is hardly any doubt that there is a great need for such a book, a book in which a young man just starting in practical electrical engineering work after college or any other school could find a clear, concise exposition of what he needs, what is done in practice, and why it is done so and not otherwise.

In general the book by Mr. Raymond satisfies this need and contains a good deal of useful information about the general theory, testing, and partly about design of modern alternating current apparatus; the first part of the book is intended for readers who wish to restore in their memory the necessary theoretical data without going into old college notes and heavy text-books.

The book can be well recommended to young college graduates and to men who already had some practical experience and are lacking necessary theoretical foundations for a clear understanding of their profession. As a text-book for students the book is hardly suitable, because it is not systematic enough and does not bring sufficiently into prominence the general ideas which are so important for a student to acquire.

Even a superficial perusal of the book shows that the author is more familiar with practical handling and testing of machinery than with the design or methods of manufacturing. Still more evident is his lack of experience in pedagogical matters, the knowledge of the ways in which to bring forward things in a correlated, systematic way, giving prominence to important things without forgetting to answer the question "why" as well as "how."

This lack of system and of clearness of exposition is especially noticeable in the first part, where the author deals with the theory of alternating currents without any experimental foundations, and where the notions of different electrical quantities appear with hardly any logical sequence in the form of clumsy formulas. In perusing the first chapter of the first part of the book one does not know for whom it was written. A college graduate certainly does not need to be reminded that a magnet has two poles; that there is Ohm's law, and that cosine is a property (?) of an angle. On the other hand, a man who does not know such things cannot learn them from Mr. Raymond's book, for his explanations are too short and not founded on a clear series of elementary experiments. The second chapter of the first part, dealing with alternating current diagrams, is written better, though here also things are brought forward without much correlation, and while pages are spent in explaining particular problems and diagrams, hardly a word is said about the general scope of alternating current engineering work, its subdivisions, and the purpose of all those diagrams and problems.

The first chapter of the second part, on transformers, is probably the best in the whole book, being written in a clear way and giving really practical and concise information on this class of apparatus. On the contrary the next chapter on alternating-current motors is not satisfactory, especially where the mathematical theory of motors is given in the form of long clumsy formulas which should frighten everybody by their very aspect. This chapter was evidently written under the influence of Mr. Steinmetz' books, but the author forgets that that which suits an analytical and critical study of the subject, hardly fits a "practical" book written for the purpose of giving young men right principles while they are starting in their practical activity. A clear physical theory of induction motor should be given first, then the performance curves and test, and finally the principal mathematical relations, for those who would care to go deeper into the subject. It seems also strange that the circle diagram of induction motor is not mentioned at all; this diagram is well adapted for testing floor and not only gives at a glance a good insight into the properties of a motor, but also represents in the opinion of the writer the best practical method for getting performance curves of the motor. As Mr. Raymond partly gives the theory of induction motor in the form of vector diagrams it seemed most naturally to complete them into the classical circle diagram.

Among commutator motors only the repulsion motor is discussed, and the compensated series motor is not even mentioned at all. A praise of repulsion motor at the end of the chapter and the enumeration of its advantages is the more out of place, in that the General Electric Co. which advocated this motor last year now has abandoned it and turned

over to the compensated series motor for alternating-current railway work.

The last part of the book is devoted to the study of alternators, and that part of it which treats the testing methods is written clearly and with a thorough practical knowledge of the subject; but wherever Mr. Raymond tries to give theoretical explanations especially upon the causes of voltage drop in the armature he looses the ground and goes around without getting at the point. So instead of explaining the armature reaction and self-induction for the case of ordinary multi-phase multi-polar alternators in which this action is comparatively simple, he tries to explain it on an artificial case of a two pole single-phase machine with a revolving armature of the direct-current type.

Finally it comes out as if we could predetermine the regulation from saturation and short-circuit tests, while it has been demonstrated by Mr. Behrend and others, that this is not the case, and that special tests are necessary for this purpose.

In summing up it seems that notwithstanding some defects the book can be well recommended to young electrical engineers and to those who would like to refresh their memory on the subject of alternating currents. It is to be regretted that Mr. Raymond did not write his book in co-operation with somebody more familiar with the theoretical part of the subject and particularly with the approved methods of presenting them in a simple lucid way. Then the wide practical experience of Mr. Raymond would find its right place in the book and make it one of the most valuable additions to our engineering literature.

V. K.

Physikalische Practicum. WIEDEMANN & EBERT. Braunschweig, Vieweg & Son, 1905. Pages xxx + 590.

The appearance of the fifth edition of Wiedemann and Ebert's Laboratory Manual of Physics signalizes the continued appreciation of the merits of this well-known work. The new edition differs from the fourth edition which preceded in 1899 chiefly in the introduction of new experiments in Electricity with a view to making the volume more useful to students in electrical engineering.

The manual in its original form appears to have been developed with special regard to the needs of students in Chemistry and Medicine as well as of the student of general physics. The addition in the present issue of an increased amount of elementary electricity is an advantage from every point of view.

E. L. N.

The School Chemistry. By ELROY M. AVERY. American Book Company, New York. Pages 1 + 411. 1904. (*Received.*)